OPTIMIZATION OF CREMA PRODUCED IN COFFEE

By

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A Thesis Submitted to The Honors College

In Partial Fulfillment of the Bachelors degree
With Honors in

Chemical Engineering

THE UNIVERSITY OF ARIZONA

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Abstract

The goal of this Honors Thesis Project was to design and test a novel coffee brewing method that results in a cup of coffee with maximized crema volume and minimized grounds remaining after filtration. Crema is an emulsion of aromatic oils, water, and gases that is naturally created when coffee grounds are brewed in hot water. Typical filtration strategies do not preserve crema, but are effective at filtering out coffee grounds. The product that was designed in this engineering design project optimized these two variables through the use of inverted filtration and stainless steel filters of varying pore shape and size. The product, named the “Crema Cup”, was designed as an attachment to the AeroPress coffee press.

Inverted filtration is the process of pushing fluids upwards through filters, rather than downward. This preserves crema because crema rests on top of the brewed coffee; the crema can move through the filters first and not be disturbed by coffee grounds settled below. Six mesh filters and three slot filters were tested (individually and in series). The best result was the 80 mesh filter in series with the 0.004” slot filter. This final filtration set up produced 4.5 mL of crema per cup and allowed only 4.8% of coffee grounds to pass through. By manufacturing the Crema Cup with polypropylene injection molding, a business selling this product could expect a 138% return on investment over a ten year period.

Final Project ChEE 443

Optimization of Crema Produced in Coffee

Submitted by

Crema Cup Crew

May 3, 2020

By signing this document, we certify that we have participated in the project, read the report and are familiar with all the information within.

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Summary

The objective of the project was to test and optimize an attachment for the AeroPress in order to produce a cup of espresso with more crema. The AeroPress is a popular coffee-making tool that employs a plastic tube to brew the coffee in and a plunger to hand press the brewed coffee through a paper filter. Traditional filtering techniques and the paper filter remove most of the crema, an emulsion of aromatic oils that enhances the flavor profile of the espresso, resulting in a subpar cup of espresso. Thus, the goal of the attachment is to preserve crema that is produced during the brew phase until the drinking stage.

The attachment allows the orientation of the AeroPress to be inverted and metal filters to be used to preserve crema that would otherwise be absorbed by the paper filter. The main drawback of using metal filters rather than paper is that more coffee grounds remain in the final cup of coffee, which is not desirable. The orientation of the AeroPress also plays a part in determining the amount of crema left over after filtering as traditional downward filtering destroys the emulsion. This attachment prototype was the starting point of the project and the semester-long expectation was that the prototype would be modified in order to increase safety and efficacy of the desired attachment. Given the COVID-19 pandemic, all in-person testing was eliminated after seven weeks and the project efforts were re-focused on economic and manufacturing research as well as general administrative work (progress presentations, applying for awards, etc.).

Prior to the pandemic, in-person testing was the forefront of this prototyping process. The first act of testing was to determine the best filter types to use to retain maximal crema volume as well as reduce the amount of coffee grounds remaining after filtration. Filter testing was split into individual filter and filter combination tests. To measure crema volume, a clear plastic version of the attachment prototype was produced that featured demarcations at every milliliter. When the coffee was pressed, a measurement was noted of the total crema volume at the top of the cup. The results of the filter testing found that, individually, the 80 mesh filter retained 4.5 mL of crema and passed 7.5% of coffee grounds through the filter. The results of the filter testing found that the combination of the 80 mesh filter and the 0.004” slot filter retained 4.5 mL of crema and passed 5.3% of coffee grounds through the filter. The entirety of the testing results

is laid out in Section 2. The attachment was also compared to several other coffee-making methods and was found to be superior to all of them in terms of crema retention.

Market information indicates a maximum ceiling of 250,000 attachments sold each year which is equal to the number of AeroPresses sold each year. However, a more reasonable estimate of total sales would be about 3.5% of this. Compared to other coffee presses and espresso machines, the Crema Cup is on the cheaper end of the spectrum. Espresso machines range from $50 to $100, and this new product would only be $30. Also, without the use of paper filters the price per cup of coffee is decreased to only $0.26 per cup. The final product comes with the desired tactile experience of coffee crema for only a fraction of the cost of a cup of espresso that can be bought from a local coffee shop.

To manufacture the product, an injection molding process was determined to be optimal. The material of choice is polypropylene, which is suitable for the injection molding process and has other desirable qualities in addition to being low cost. Polypropylene has a good heat tolerance and is non-toxic, which is crucial for handling hot liquids.

Overall, it is recommended that the project move forward as it is clearly a viable business. The logical next steps for the project would be to move onto static mixer testing which would entail 3-D printing prototypes with different mixing grids.

Contributions by Each Team Member:

Mikayla Caputo

- Summary
- Theory/Prototype Description
- Safety and Environmental Factors
- Conclusions and Recommendations
- Contributed to all class assignments and testing throughout the semester

Richie Curradi

- Theory/Prototype Description
- Materials and Methods
- Overall Process Description, Rationale, and Optimization
- Final Design and Recommendations
- Contributed to all class assignments and testing throughout the semester

Nate Marshall

- Introduction
- Results and Discussion
- Overall Process Description, Rationale, and Optimization
- Economics
- Equations
- Contributed to all class assignments and testing throughout the semester

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- Summary
- Introduction
- Experimental Section
- Conclusions
- Overall Editing/Revision/Formatting of Report
- Contributed to all class assignments and testing throughout the semester

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Section 1: Introduction

Coffee is a staple product in most people's lives with more than half of all Americans drinking at least one cup a day. The demand for delicious home-brewed coffee is higher than ever as many families seek to cut costs by avoiding takeout coffee. There are many popular alternatives for making coffee at home such as the French Press or the Keurig. While these home alternatives are great for producing a good cup of coffee, they do not make a quality espresso. Espresso is a form of coffee that is traditionally made by forcing steam at a high pressure through finely ground coffee beans in a machine. The resulting coffee is richly flavored and features an emulsion of aromatic oils, known as crema, on the surface. This crema is extremely important in identifying a proper espresso and is lost when traditional home-brewed coffee methods are used.

Espresso machines are expensive both to buy and maintain in addition to requiring a good amount of skill. Thus, the challenge at hand is to produce a quality cup of espresso at home without a machine. To solve this problem, a prototype of an attachment for the AeroPress has been created which maximizes crema retention and minimizes the amount of grounds that could seep through filters. The AeroPress, a popular home brewing method, is simply a plastic tube with a plunger and a filter which uses hand pressing to create a cup of coffee. The attachment, appropriately named the Crema Cup, is a cylindrical piece of polypropylene that fits directly onto the AeroPress. By creating an attachment, the product retains aspects of the simple brewing process that the AeroPress is renowned for while enhancing the final cup of coffee.

The main work done in the project was to optimize the attachment and create a manufacturable final product. It has been estimated that it could be possible to capture 3.5% of the AeroPress market which is judged to be about 250,000 devices sold each year. Within the at-home coffee making market, comparable presses range in retail cost from $17 to $30. Priced by the cup, the attachment is shown to be a cost-friendly alternative with the results displayed in Table 1 in Appendix A. By creating a superior and inexpensive product it could be very reasonable to capture a large portion of this consumer demand.

Section 2: Product Design, Experimentation, and Results

I. Theory, Prototype Description, and Introduction

Using the traditional AeroPress, coffee is brewed by mixing hot water and ground coffee beans in the body of the press. This mixture is then hand-pressed downwards through a paper filter to remove grounds. The two main issues that cause the AeroPress to lose most of the produced crema is the use of traditional filtration as well as the paper filter. These issues are resolved by using the attachment prototype. Other commercial options for resolving this issue are to purchase an espresso machine or buy espresso at a gourmet coffee shop.

Traditional filtration, which moves fluid downwards, greatly reduces the amount of crema retained because as an emulsion it is inherently delicate. By forcing the crema downwards, the emulsion gets dispersed and filtered by the grounds. By using inverted filtration, which pushes the coffee upward through the filter, this problem is avoided by keeping the grounds and the crema separate through the filtration process. The tradeoff with using inverted filtration is that when coffee is pressed through fine holes in the filters, vertical geyser-like jets of hot coffee can form, which introduces a spill hazard. To reduce the formation of geysers, a set of square baffles were implemented above the filters which allow the bulk fluid to pass through while acting as a barrier for the geysers in addition to acting as a static mixer. This pattern also allows users to easily press the coffee so only one fluid motion is necessary.

To resolve the issues caused by using paper filters, a set of metal filters were substituted. Paper filters do an excellent job of filtering out coffee grounds, but they destroy the crema. The converse is true of metal filters. The types of filters experimented with were wire mesh and slot filters, which can be made available in many sizes. The best filter combination used a wire mesh filter with larger holes in series with a slot filter. Thus, the mesh acts as a pre-filter that removes larger coffee grounds that would clog the smaller slot filter. The slot filter then removes the remaining smaller coffee grounds to an acceptable amount so that the final cup of coffee is drinkable and not gritty.

Another significant factor that went into the design of the Crema Cup prototype is user friendliness. When using the Crema Cup, the baffles were incorporated for the purposes of protecting the user and for re-frothing some of the crema that got lost in the filters. In other machines, such as the Mr. Coffee single-serve espresso maker, there is an attachment that needs to be used to froth milk manually to make a similar texture as crema. This makes it more inconvenient for the user of Mr. Coffee since users have more parts to clean and they have to learn how to froth milk. With the Crema Cup, the user only has to clean the apparatus and it is easily storable. Coffee machines like the Keurig and Mr. Coffee are large and bulky, making them more difficult to store. Although the Crema Cup requires more attention for the entire brewing and press processes, the convenience of a simple press is desirable in many cases. The last factor in consideration for user friendliness is the time it takes to brew the coffee from start to finish. With the Mr. Coffee machine, preparing, brewing, and creating the final espresso product takes about 15 minutes for the average person. The Crema Cup cuts that time down to 3 and a half minutes. Overall, the user-friendliness of the Crema Cup is much more desirable than that of electric coffee machines.

A costing comparison analysis was performed to determine how many units could be sold per year and how the cost of the Crema Cup would compare to other machines. The AeroPress that was used for testing was compared to three other espresso machines on the market, the Bodum French Press, the Keurig K-compact, and the Mr. Coffee single-serve espresso machine. It was found that the Bodum French Press had the lowest cost at $16.99, and the Mr. Coffee had the highest cost at $99.99. The Bodum French Press, modified AeroPress and Mr. Coffee all had the same cost per cup of coffee at $0.26, while the Keurig had a cost of $0.63 per cup of coffee. It was estimated that 250,000 units of the AeroPress are sold each year, so it is assumed that this prototype would be able to reach that value. The full cost comparison can be found in Table 1 in Appendix A.

Static mixing played a small role in the optimization of our prototype, but significant testing was not done because it was scheduled to occur in March and April. This variable has the potential to impact both dependent variables of crema volume and percentage of grounds remaining. It is hypothesized that it would have a larger impact on crema volume, because it is an emulsion of oils, gases, and water (Goodwin). Static mixers are essentially a set of baffles in pipes that helps to mix the fluids being transported. As Edward Paul states in the Handbook of Industrial Mixing, “all static mixers employ the principle of dividing the flow into substreams, distributing the substreams radially, and recombining them in a reordered sequence.” Static mixing can take place in all three flow regimes: laminar, transitional, and turbulent flow. The flow is determined by the pressure gradient, the fluid characteristics, and the pipe characteristics, as shown in Equation 1.

$$\frac{\ }{\ } \qquad (1)$$

In the case of the Crema Cup, static mixers could help to develop and mix the foam emulsion. The optimized prototype used a checkerboard-like pattern that acted as a static mixer. Upon further research, it was determined that turbulent regimes mix emulsions significantly better than laminar regimes, and more baffle patterns would need to be tested to determine if this would be feasible.

II. Materials and Methods

The prototype, shown below in Figure 1, consists of four different parts starting with part 1 on top to part 4 on the bottom:

1. The upper chamber of the attachment is a clear polyethylene pipe. This part was designed for storage of the brewed coffee and crema prior to serving. The upper chamber was printed from clear plastic and 1 mL demarcations were added during the testing phase in order to accurately measure the crema volume during testing.

2. The filter housing of the attachment is 3-D printed and made of Tough 2000 Resin from Formlabs. This part holds the two stainless steel filters and is sealed by a silicone o-ring. It also features a quarter-turn tapered locking mechanism which securely attaches to the AeroPress. The entire attachment is made up of parts 1 and 2 only.

3. The AeroPress body is also referred to as the brewing chamber. This piece holds the brewed coffee prior to filtering. The lip of the chamber allows the filter housing to lock onto it.

4. This part is the AeroPress plunger. When making coffee with the attachment, a downward force is applied to the AeroPress body so that the plunger moves upward into the chamber and the coffee is pushed through the filter.

Figure 1: The AeroPress and Crema Cup attachment, with each part labeled

All of the testing that took place was focused on optimizing the filters. The dependent variables of the filter testing were the percentage of grounds remaining after filtration and the volume of crema. The independent variables were the filter pore sizes, filter pore shapes, and filter configurations. To reduce variance between experiments, the following parameters were kept constant: the coffee beans, the coffee bean grinder, the scale, the paper filters, and the experiment location as shown in Table 2. These parameters are held constant in addition to the variables laid out in the experimental plan below.

Table 2. Constant Parameters

Parameter	Item Description or Value
Coffee beans	Kirkland ‘Guatemalan Organic Coffee Beans’
Bean grinder	OXO Brew ‘Conical Burr Coffee Grinder’
Scale	Homgeek ‘Professional Digital Mini Scale’
Paper filters	BUNN ‘Coffee Filters’
Experiment location	2903 North Silkie Place, Tucson AZ, 85719 4160 West Post Road, Chandler AZ, 85226

The experimental plan is summarized as follows:

1. Weigh out 15 grams of coffee beans and record exact weight from scale.
2. Preheat the oven to 200 F.
3. Place the beans into the grinder and grind at setting 6.
4. Re-weigh the ground beans.
5. Pour the ground beans into the AeroPress with the plunger fully retracted.
6. Boil 250 mL of water with the electric kettle.
7. Pour 50 mL of water over the grinded coffee beans (measured using the AeroPress markings) but do **not** stir and start a timer.
8. After approximately 30 seconds, add the other 200 mL of water. While pouring, stir the mixture.
9. After a total of two minutes have passed since starting the timer, hold the body of the prototype and push downwards until all the coffee has been filtered and is contained in the chamber of the attachment.
10. Record the total volume of crema produced to the nearest half mL using the 1 mL demarcations.
11. Put two paper filters into a colander in a sink.

12. Pour all the coffee into the filters to catch all the remaining grounds, letting the coffee go down the drain.
13. Remove the filters from the colander and place into ceramic ramekins without spilling grounds.
14. Put these ramekins into the oven and allow to dry. Time may range between 25-40 minutes depending on the amount of grounds present.
15. Re-weigh the dried filters and record the results. These results minus the weight of two filters represents the total mass of grounds that passed through the tested filter.
16. Repeat the test with the next required filter or series of filters. The same filter should be tested multiple times to produce an average result in the experiment.

A video example of using the crema cup is shown in the supporting files titled “Video 1 - Crema Cup In Use.” This video only shows the pressing motion, and does not include the entire experimental process.

III. Results and Discussion

To analyze the results, crema volume and the amount of grounds remaining after filtration are the most important measurements. In order to calculate the amount of grounds remaining, the weight of the filters was standardized by averaging the weight of 10 of the filters as shown in Table 3 in Appendix A. A lot of time was saved by finding an average weight for the filters rather than weighing each filter every run. This value was used in the subtraction protocol for determining the final weight of the remaining grounds. This final weight divided by the initial weight of grounds (multiplied by 100) is the percentage of grounds that passed through the filter.

In a similar time-saving fashion, it was desirable to find out how many runs would be required for each experimental set-up that would limit outliers. To do this, the experiment was run on one filter seven times. The standard deviation was calculated for the set of results for the filter and was found to be low enough that only two runs were required for each filter set-up. The results for this experiment are found in Table 4 in Appendix A.

For the sake of simplicity and cost, it was decided to first test mesh filters alone in the prototype. Mesh filters were found using the supplier McMaster-Carr under the name ‘Stainless Steel Wire Cloth Discs’ (Fig. 2). There were four main reasons why testing began with mesh filters. First, they were cheap. Each filter came in a pack of 25 and each filter only cost $0.47. Second, they were commercially available and had a short lead time. Third, they came in many diameters, so it was easy to find the correct size for the prototype. And fourth, there was a large range of choices for the number of wires per square inch which is the main driver for determining the size of particles that can pass through the filter.

Mesh filters ranging from 20 to 100 wires per square inch are known to allow fluids to pass through relatively easily. This is important for the user experience as it is easier to press the coffee. As a point of reference, the 20 mesh filter has an opening size of 0.034" and the 100 mesh filter has an opening size of 0.006". Additionally, the open area in these filters were large in scale, ranging from 30% to 46% open. It was hypothesized that this large open area would allow the emulsion to pass through without being broken by the filter. Each filter was tested to determine the volume of crema and the percentage of grounds that remained in the cup after pouring. The results are shown in Table 5 in Appendix A. Below, in Figure 3, the results are displayed.

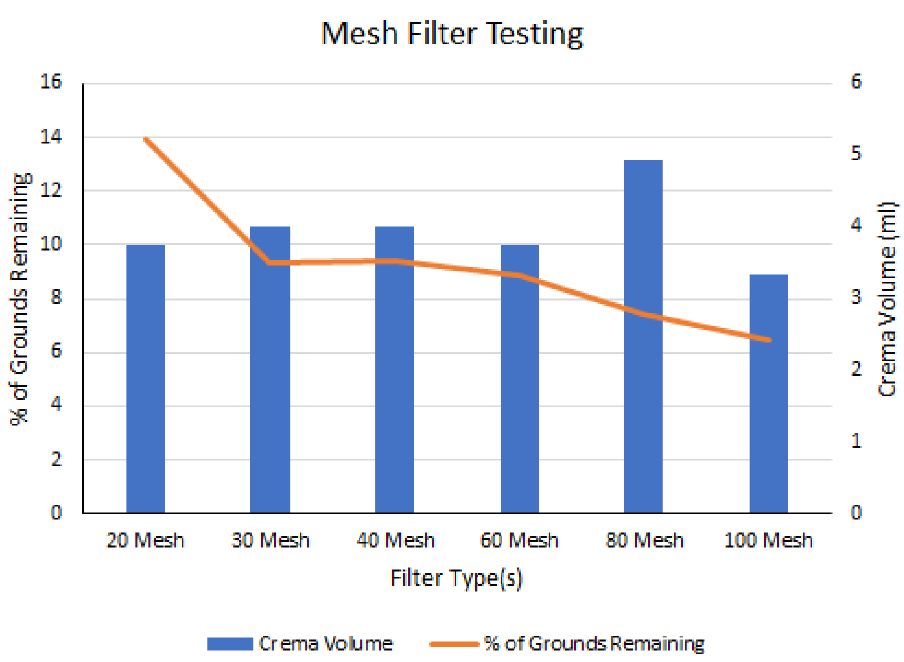

Figure 3: Mesh Filter Testing Results

It is clear from Figure 3 that increases in the number of wires per square inch resulted in better separation of solids from liquids. This is equivalent to saying that a decrease in opening size correlates to a decrease in the percentage of grounds remaining. This makes logical sense as decreasing the area for particles to go through would lead to fewer particles passing through. The 100 mesh filter performed the best in terms of remaining grounds, allowing only 6.4% of grounds to pass through the filter.

In Figure 3, the 80 mesh filter performed the best for crema volume, resulting in nearly 5 mL of crema preserved. However, there did not seem to be much of a correlation between crema volume and mesh size. It was hypothesized that these mesh filters did not reach a limiting point that would prevent crema from staying together. This directed the decision of which filter to test next. So-called "slot filters" were theorized as a possible way to push the limits of pore size and open area (Fig. 4). The slot filters were custom-made by the company Etch It. The filters have slotted pores on 0.003" thick circular pieces of stainless steel. The pores are 0.1" inches long and were made to vary from 0.004" wide to 0.01" wide. The goal of these filters was to have small widths that would not let many particles through but long slot lengths to reduce the disturbance on the crema. These filters were tested individually. The slot filter results are represented in Table 6 (Appendix A) and displayed in Figure 5 below.

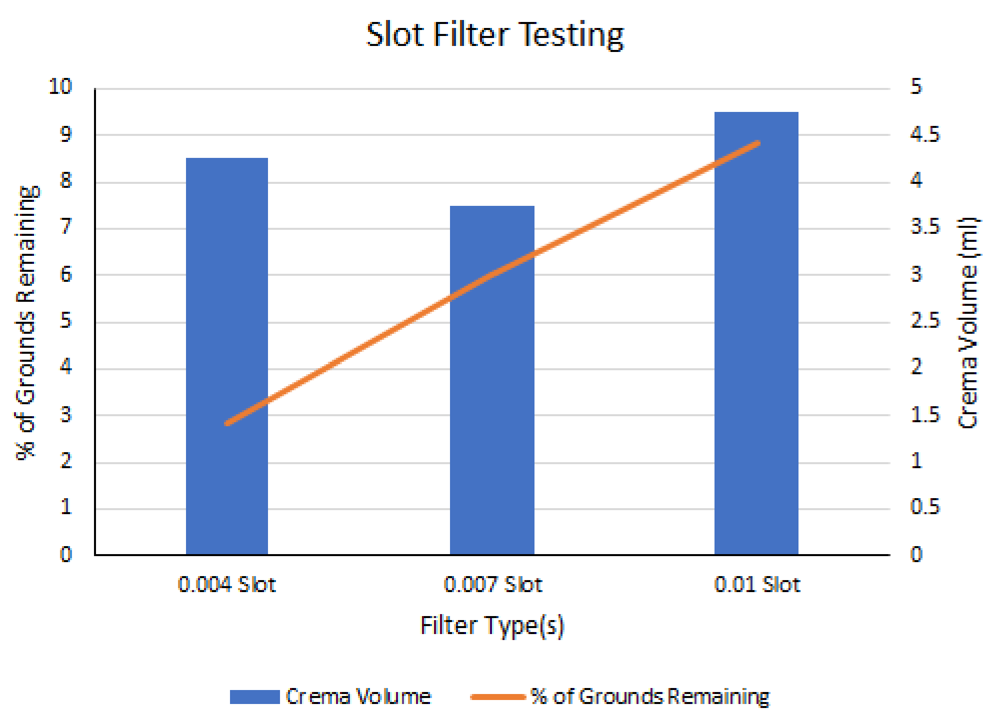

Figure 5: Slot Filter Testing Results

Figure 5 shows that the slot filters exhibited a directly proportional relationship between the percentage of grounds remaining and the slot diameter with the smallest slots having the lowest percent of grounds remaining. This relationship is represented in Equation 2 and shown in Figure 6 below. The R Squared value of the linear fit is 0.9988.

(2)

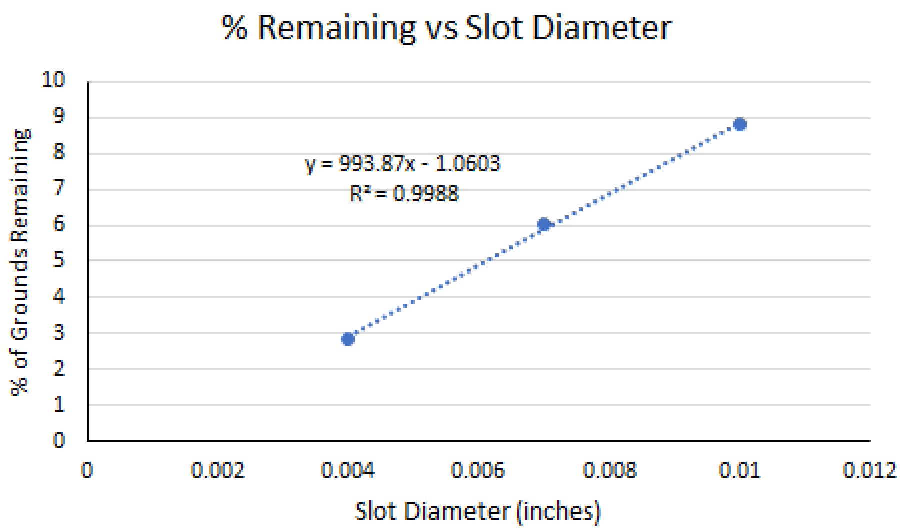

Figure 6: Percent Remaining vs Slot Diameter

Clearly, the 0.004” slot filter was the best at filtering the grounds. This was expected because it has the smallest pore diameter. The 0.01” slot filter preserved the most crema. Again, this was expected because that slot filter had the largest open area. It is unclear as to the reasons why, but the 0.007” slot filter’s crema results were not in between the values of the other two filters. It was clear that there was variation in crema preservation.

It is important to mention that the 0.004” slot filter, while clearly the winner in terms of results, was not user friendly. When pressing the coffee through this filter, the filter quickly became clogged. Because of this, it took a significant amount of force to press the coffee through. It simply would not make sense to sell this as a filter alone. However, this led to another innovation in filter design. The mesh filters were relatively successful in removing grounds. So, using a mesh filter as a “pre-filter” was determined to be the next step in the testing process. The 80 mesh filter was the most balanced pre-filter; it maximized crema without letting a significant amount of solids pass through. The 80 mesh filter was tested in series with each of the slot filters. The hypothesis was that the mesh pre-filter would stop large particles and the slot filters would stop small particles, but not get clogged. The results of these tests are shown in Table 7 and Figure 7.

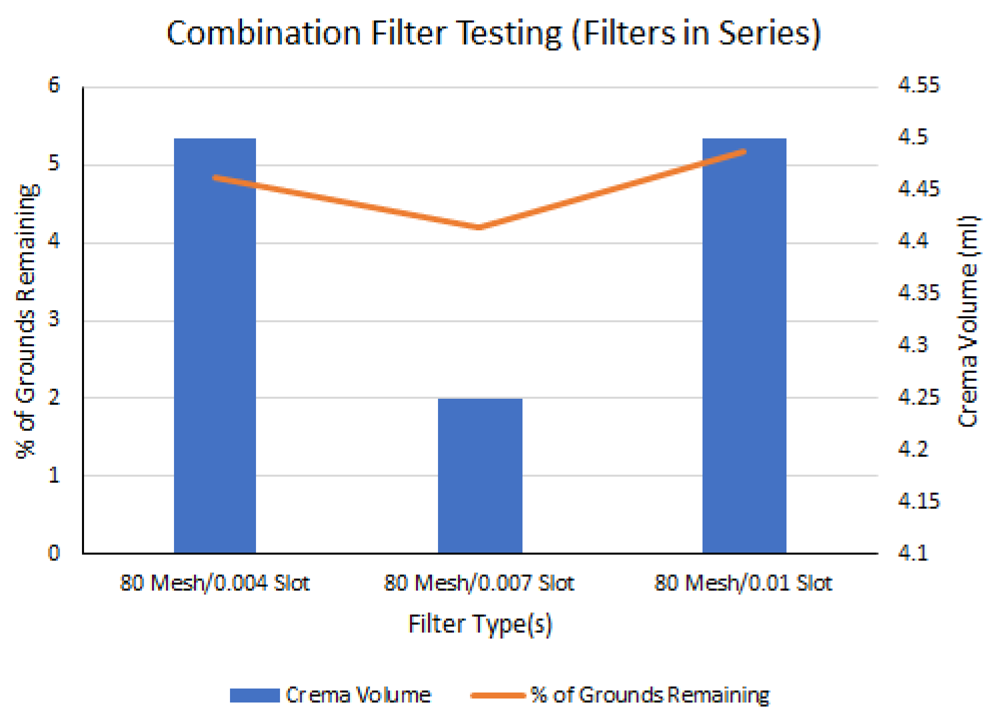

Figure 7: Testing of Filters in Series

The 80 mesh filter in combination with the 0.007" slot filter resulted in the least crema and the least solids. The 80 mesh filter in combination with the 0.004" slot filter resulted in the same amount of crema as with the 80 mesh filter in combination with the 0.01" slot filter: 4.5 mL. It was determined that crema volume was the most important factor in choosing the best filter set-up. Because the 80 mesh filter in combination with the 0.004" slot filter resulted in slightly better solid filtration than the 80 mesh filter in combination with the 0.01" slot filter, the 80 mesh/0.004 slot was chosen as the optimal set up. This filtration set up results in 4.5 mL of crema and only 4.8% of grounds remaining in the cup. This was compared to the French Press and Keurig. The Keurig creates no crema, and the French Press preserves 1 mL of crema. The French Press lets 7.7% of grounds to pass through its filter, indicating that the Crema Cup's filtration is more effective. All of the experimental results are represented in Figure 8 in Appendix A.

IV. Final Design and Recommendations

The final design features the 80 mesh pre-filter and a 0.004" slot filter as was determined to be the best combination through testing. A recommendation to enhance testing results is to perform a particle distribution test of the remaining grounds. These results would guide filter choice and provide some insight into the filtering and mixing taking place. Also, without further testing, the original static mixing grid with square baffles will remain the chosen design. Moving forward, more testing on the static mixer is highly recommended. It is entirely possible that with added testing, another grid configuration could prove to perform better than the initial set of baffles. Another recommendation for testing is to measure the crema produced before filtering by adding 1 mL demarcations to the AeroPress. This would standardize the crema measurements and give more information about the properties of the crema in relation to the independent variables.

Currently, the device will be made out of polypropylene. This material was selected as it has a high heat tolerance, is dishwasher safe, reusable, easy to clean, and BPA-free. This is also the material that the AeroPress is currently made out of. It is also an appropriate plastic for blow-molding, as is discussed in Section 3. The filters are made out of stainless steel while the sealing O-ring is made out of silicone, both of which are compatible with the desired temperatures and fluids in the process.

The final product also needs to have increased safety measures embedded in the design. Currently, there are stability concerns due to the height of the set-up. To solve the stability issues, it is recommended that either a wider base or a fitted tripod be added to the body of the device. Another option moving forward with the prototype is to create a stand-alone device rather than an attachment. This would allow the base to be widened as necessary for stability and removes the product's reliance on the AeroPress. Being independent from the AeroPress design eliminates the chance of having the attachment become obsolete with changes to the AeroPress. This is the ultimate goal of the Crema Cup project given enough time to test every option and build.

Section 3: Overall Process Description, Rationale, and Optimization

After the product was designed and optimized for consumer use, a manufacturing method needed to be implemented for mass production. While the prototype was conveniently made with a 3D printer, this process is slow. In order to scale production, it was decided that injection molding (IM) would be most efficient and economical. According to CustomPart.net, "Injection molding is the most commonly used manufacturing process for the fabrication of plastic parts." The main reasons for this are that it creates less waste than most machining methods, it produces consistent results, and the cost for each part is low after the initial investment for the mold. There are, of course, downsides to the process as well. The design of the product cannot have overlapping pieces and there is a large barrier for entry as injection mold tooling is very expensive.

The injection molding process requires an injection molding machine (Fig. 9 in Appendix A), a mold, and raw plastic (Xcentric Mold & Engineering). The IM machine is made up of two parts: the injection unit and the clamping unit. The mold, which resides in the clamping unit, is a machined steel piece that can withstand heat, pressure, and thousands of cycles. The raw plastic for this process comes in the form of polypropylene pellets. These pellets are produced by some of the largest chemical companies in the world such as Dow, BASF, LyondellBasell, and ExxonMobil.

The process cycle of IM can be summarized into four basic steps (CustomPart.net): clamping, injection, cooling, and ejection. These steps are explained below, with most of the information provided by CustomPart.net:

1. Clamping: There are two halves to the steel mold itself. One of these halves is static, and the other moves to open and close the mold, allowing material to enter and exit. The first step in the injection molding process is the closing, or clamping, of the two halves. The mold is clamped shut with a large force in order to ensure that molten plastic cannot leak out of the sides.

2. Injection: Plastic pellets are fed to the IM machine where they are melted by high temperatures and pressure. After the plastic has melted, it is injected into the mold, filling it and forming the plastic piece. This is represented in Figure 10 in Appendix A.

3. Cooling: After the mold is filled, the plastic must cool and harden. The time required for cooling depends on the plastic and the size of the piece.

4. Ejection: After the part has cooled, it must be forced out of the mold. The clamp on the mold is released and the piece is pushed out. The plastic piece will not fall out of the mold by itself because the plastic, during cooling, shrinks around the mold. The finished plastic piece falls into a container that holds a previously determined number of parts, referred to as the batch size. After the piece is ejected from the mold, the mold is ready to close, clamp, and create another unit.

Once the plastic is finished, it will be placed on a conveyor belt to go through an assembly line. Here on this line, different stations will require an additional component to complete the product. The first station will be required to attach the filters and the silicone O-ring to keep them snug and firmly in place. Simultaneously, boxes will be constructed (either by hand or machine) to place the product in. Once the product has all add-ons, it is completed. This completed product will be put back on the conveyor belt. At the end of the belt, instructions will be put into the box with the product. The box will then be put onto a pallet to allow for storage in a warehouse.

Typically, injection molding is contracted out to companies that specialize in plastics molding processes. These companies are contracted to make a certain number of a product and charge for materials and machine time. The molds are interchanged when a different product is being manufactured. Manufacturing sites that use injection molding are typically run using assembly lines to increase efficiency. These plants can be optimized using lean engineering principles. Since designing the manufacturing plant was not in the scope of this project, a brief overview of how a typical plant could be optimized is discussed below.

According to Eliyahu M. Goldratt, manufacturing plants should aim to increase throughput, decrease inventory, and decrease operational expense. There are dozens of ways to optimize these variables. One convenient way to do this is to use a pull system with Kanban cards. Kanban cards indicate to an upstream operation that a part is needed downstream. By operating under a pull system, inventory is decreased because production quantities are forecasted in real time. Throughput also increases because there is less waiting for upstream operations to catch up.

In the case of the Crema Cup, this would be akin to sending the plant an order when a customer buys the product, and the plant starting production of the product at that time. Additionally, reducing batch size decreases inventory and operational expense. In an ideal situation, products would flow like fluids do through pipes. Continuous flow in chemical plants is essentially taking the limit of a process as batch size approaches zero. Batch sizes of one is the goal for products like the Crema Cup. In addition to reducing batch size, using “C” shaped workstations optimizes the floorspace within a plant. This reduces operational expense because less square footage is needed in the plant. While many more methods can be used to optimize a manufacturing plant, these basic principles are often used in industry as steps to achieve a lean system.

To sum up, injection molding is a cost effective and time tested method for plastic piece manufacturing. An assembly line to put together the device is effective in preparing for sales and shipping. Implementing lean manufacturing principles in the plant would reduce cost and increase productivity, resulting in a highly effective and low waste business.

Section 4: Safety/Environmental Factors

I. Safety

The safety of using the Crema Cup was evaluated by performing a failure mode and effects analysis (FMEA). Although there are no requirements for personal protective equipment while using the Crema Cup, there are several safety precautions that should be followed in order to ensure the safest experience for the user.

Three scales were used to determine the risk factor of each process failure. The first of these scales is the severity scale, which measures how dangerous the failure is to the user. A severity ranking of 10 indicates that the failure occurs without warning and will most likely cause death, while a ranking of 1 indicates that there is no effect on the user. The next scale is the occurrence scale, which evaluates how often the failure may occur. An occurrence ranking of 10 means that the failure will occur more than once per day, while the ranking of 1 means that the failure will occur once every 7 years or so. The last scale is the detection scale, which indicates how likely it is for the failure to be detected by the user. A detection ranking of 10 means that it is almost impossible to know that the failure is happening, while the ranking of 1 means that the failure will almost always be detected by the user. The risk priority number (RPN) was then determined by the following equation.

(3)

It was decided that a risk priority number above 49 would be labeled a critical failure. Based on these three scales, there were two potential failures that would need to be assessed to minimize danger to the user. During the brewing process, the user might knock over the crema cup and spill the contents. This would cause a loss of coffee and the boiling water could potentially burn the skin of the user if they are not alert. This event would most likely be caused by the instability of the device, since that was a common problem that occurred during the testing phase. To prevent this from happening, it is recommended that the user use both hands when brewing coffee with this device. During the coffee press step of the process, the user may experience failure in the O-ring due to heat deformation. This could cause leakage of coffee from the apparatus, leading to burns on the user’s skin. During testing, it was observed that the o-ring started to shrink over time, eventually becoming too small to seal the connection between the crema cup to the AeroPress. It is recommended that the user change out the o-ring every six months to prevent this failure from occurring. Both of these failures received a 5 in severity, a 5 in occurrence, and a 3 in detection, giving them an overall RPN of 75.

According to FMEA analysis, anything with a severity of 10 is in need of corrective action. The two failures that fall under this condition are improper filter placement and breaking of the crema cup. To ensure that these failures do not occur, it is recommended to always double-check that the filters are in place and do not exert too much force on the Crema Cup when pressing your coffee. These recommendations should be labeled as warnings in the instructions for use.

There are several factors of the Crema Cup apparatus and process that can lead to burns or serious injury of the user. Many failures that include leakage as a consequence are significant to manage for this reason. When assembling the Crema Cup, it is important to ensure that the apparatus and AeroPress plunger are aligned correctly, and the filters and o-ring are properly placed and secured. Caution should be taken when pouring the boiling water into the apparatus to avoid spillage of hot liquids and the hot liquid should never be touched directly by the user. Adding an excess amount of water to the Crema Cup could result in overflow, which could cause burns, so accuracy is significant when measuring the amount of water that is being added to the apparatus. Lastly, the apparatus and filtered out coffee grounds get very hot during the brewing and pressing processes, so letting the apparatus cool to room temperature before cleaning it would prevent any burns due to touching hot materials.

In addition to burns, it is important to point out that placing fingers in the pinch point between the AeroPress and the Crema Cup could lead to the skin being broken or squeezed, so when handling the apparatus, place hands only on the upper and lower cylinders. Other failures include consequences such as loss of coffee, wasted grounds, or incorrect concentrations, but these failures were not scaled to be as significant as those that lead to user injury. The full FMEA can be found in Table 8 in Appendix A.

There are also several safety factors that come into play when manufacturing a product via injection molding. When loading granules, strain injury can occur from manual lifting, and cuts and crushing of the hands can be caused by entanglement by reaching into the auger or entrapment in closing molds. During the molding process, molten polypropylene can cause thermal burns and lung damage can be caused by breathing in toxic fumes. Dust particles that reach the air can cause eye damage, breathing problems, lung damage, or risk of explosion. Personal protective equipment, such as earmuffs, goggles, and respirator to filter the air being inhaled are required to be worn by employees in the manufacturing plant.

II. Environmental

Polypropylene is a recyclable thermoplastic polymer, so it can be reused and reprocessed into other products. If not recycled, the Crema Cup should be disposed of in a landfill or by controlled incineration. Polypropylene is most dangerous in the gaseous form. Toxic fumes from the plant should not be released into the air, and the plastic itself should not enter drains, sewers, or other watercourses. Ventilation should be present throughout the plant to ensure the air quality within the plant is up to code, and fumes should remain at a safe concentration. Emissions from ventilation should comply with the environmental protection legislation, so they should be reduced where possible.

It is estimated that 2.25 billion cups of coffee are consumed each day across the globe. If half of these cups were made in an 8-cup batch, that would equate to 140 million paper filters being discarded each day. That means that 51.3 billion paper filters are thrown away each year, filling the landfills with the sweet aroma of coffee. If all of these filters were put together, there would be 227 acres of land filled with just paper filters from one year. According to Recyclebank, paper filters that are used for coffee brewing are "unsuitable for the recycling process." When coffee comes through the filters, oils from the grounds get trapped in the filters that decrease the quality of the paper, therefore making them unrecyclable. The metal filters being used in this apparatus are reusable for about one year, or roughly 400 cups of coffee. With the use of the new metal filters, the overwhelming amounts of paper filters filling the landfills would be eliminated and less waste would be generated.

Section 5: Economic Analysis

Economics Overview and Summary

The market for in-home coffee makers and presses is immense. More than half of Americans drink coffee, and 79% of those people make their coffee at home (National Coffee Association). Because of this, there has been a large influx of at home brewing methods hitting the market. Generally speaking, each new method introduces something new to the world of gourmet coffee. For example, the “Pour Over” method, which became wildly popular in 2012 and 2013, which allows the user to simulate the drip coffee process and adds flexibility to flow rates and water temperature. The Crema Cup attachment fits into this category of gourmet brewing methods and its economics were analyzed as such.

The AeroPress is estimated to sell 250,000 units per year. As an attachment, this was considered the absolute upper limit of sales. In analyzing the first ten years of sales for such a product, it was assumed that an average of 5 +/- 1.5 percent of the AeroPress market could be captured. Assuming the lower end of this scale results in 3.5% market capture. However, sales were determined to ramp up linearly, beginning with 1000 units sold in the first year. After ten years, 16500 units would be sold annually. Revenues were estimated to be $2.6 million over ten years with investments of just under $1.1 million put towards scaling production and sales. After ten years, a total of over $1.5 million in profits would be realized, leading to a return on investment of 138%. Figure 11 and Table 9 below display the economic values over the first ten years of production.

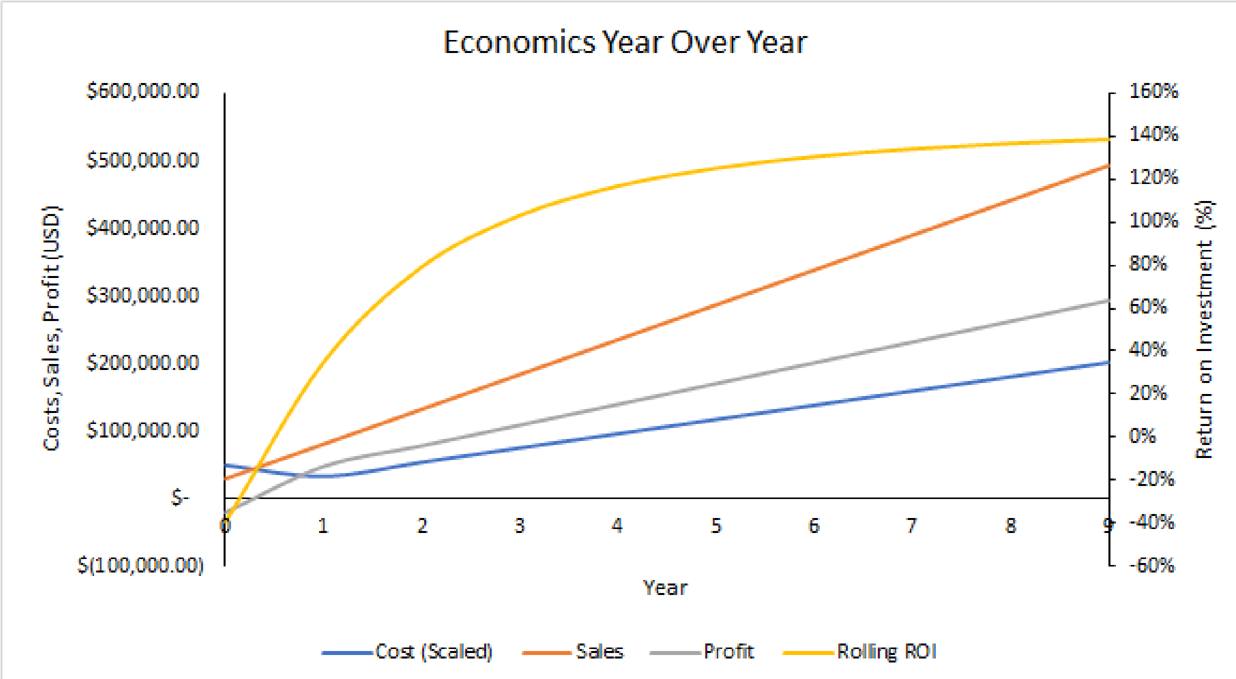

Figure 11: Costs, Sales, Profits, and Rolling Return on Investment

Table 9: The year over year economics of manufacturing and sales.

Year	Units Sold	Cost (Scaled)	Sales	Profit	Rolling ROI
0	1000	$ 49,635.00	$ 29,950.00	$ (19,685.00)	-40%
1	2722	$ 33,034.17	$ 81,530.56	$ 48,496.39	35%
2	4444	$ 53,933.33	$ 133,111.11	$ 79,177.78	79%
3	6167	$ 74,832.50	$ 184,691.67	$ 109,859.17	103%
4	7889	$ 95,731.67	$ 236,272.22	$ 140,540.56	117%
5	9611	$ 116,630.83	$ 287,852.78	$ 171,221.94	125%
6	11333	$ 137,530.00	$ 339,433.33	$ 201,903.33	130%
7	13056	$ 158,429.17	$ 391,013.89	$ 232,584.72	134%
8	14778	$ 179,328.33	$ 442,594.44	$ 263,266.11	137%
9	16500	$ 200,227.50	$ 494,175.00	$ 293,947.50	138%

I. Manufacturing Economics

While the profits for any company are determined by many factors, the most important factor was determined to be the margins of producing the Crema Cup. All other costs associated with the business dig into the profitability of manufacturing the Crema Cup. These costs include the initial cost of the injection mold, the cost of running a business, and marketing costs. Therefore, maintaining a low overhead cost is of the utmost importance.

It was determined in Section 5 that the product would need to be manufactured using injection molding. This method allows for high throughput and minimal waste, especially when compared to 3D printing on a large scale. Although efficient for making the prototype, 3D printing is not economically feasible in mass production. Injection molding processes require a physical mold. An example of a typical mold is displayed in Figure 12 in Appendix A. In determining the cost of a mold, there are three inputs: Rapid Prototyping, Insert Tooling, and High Production Tooling (Fig. 13). High Production Tooling was the most expensive of the three since the finest quality is being used in the product. This combination results in an injection mold cost of $37,500 according to Rex Plastics, which is the largest fixed cost for production.

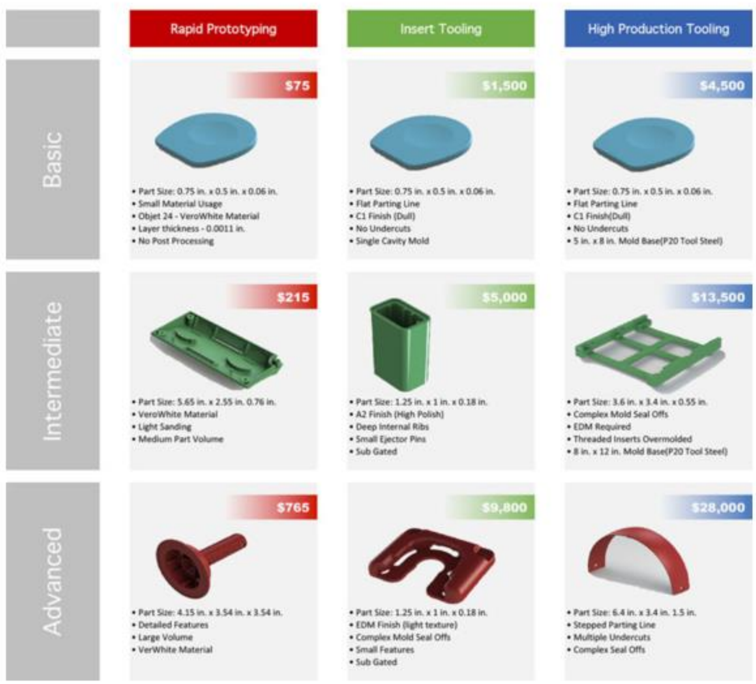

Figure 13: Estimations Of Typical Injection Molds

Once production starts, there are material and labor costs that need to be evaluated. Using a personal contact at Techmold in Tempe, Arizona, it was determined that the cost of polypropylene would total around $5 per unit. The 80 mesh filters (technically named 304 Stainless Steel Wire Cloth Discs 2-3/8" Diameter, 80 x 80 Mesh Size) cost $0.47 per unit (McMaster-Carr). The silicone O-ring used to seal the filters into place costs $0.12 per unit. The actual retail box packaging for the device is estimated to cost $0.50 according to the Senior Packaging Engineer at Four Peaks Brewing Company. Unfortunately, due to the fact that this is a commercial product and companies want to stay competitive, there is not a lot of data on costs associated with packaging and specialty items. The 0.004” slot filter is a machined good that is not currently manufactured. Therefore, it is estimated to be on the high end of the production cost at $2.00 per filter. This brings the total cost per unit to be $8.09. Since a typical price point for similar gourmet coffee products is at least $30, the price for the Crema Cup was determined to be $29.95.

While at first glance, it may look like the product would easily create profit, these costs do not include administrative costs such as logistics, marketing, storage, and labor. These overhead costs are recommended to be no more than 35% of the total revenue of the company (FP Advance). For a conservative value, the overhead percentage was valued at 33%, or ⅓, of the total revenue of the company. Essentially, the base cost of manufacturing ($8.09 per unit) was scaled by 1.5 to achieve this result. With these costs and the assumptions for market capture in the previous section, the year over year return on investment was calculated using Equation 4. The table and graph below show the economics of producing and selling the Crema Cup over time.

(4)

II. Economic Hazards

Products related to anything that humans and animals ingest receive a lot of scrutiny from regulators and consumers. Due to this fact, the Crema Cup has economic hazards associated with any problems that arise during consumption of its product. The largest economic hazard to this product is associated with the possibility that hot liquids can be spilled onto consumers, causing burns. If this were to occur, lawsuits could prohibit the use of the Crema Cup or cause irreparable economic damage to the company. In the United States, there are multiple examples of lawsuits involving burns caused by companies who were negligent in their operations and practices. The most famous example is Liebeck v. McDonald's Restaurants. Stella Lieback accidentally spilled a McDonald’s coffee onto her groin, causing third degree burns. Lieback was awarded $2.86 million dollars after it was shown in court that McDonald’s was negligent in their serving of coffee. The coffee that they served was 180 - 190 degrees Fahrenheit (Consumer

Attorneys of California). At this temperature, the coffee was not safe for consumption or contact with the skin. In order for the Crema Cup to be profitable, the manufactured device would need to be ensured as leak-proof. On top of that, directions for use would need to be very direct about the risks and how to mitigate them. It would be wise for these directions to be read over by law professionals in order to ensure that any risks associated with coffee consumption are as low as they can be and that users are aware that if they stray from the directions, it increases the risk of hazardous results.

Another economic hazard is associated with the success of small businesses. Forbes estimates that “only about one in three small businesses get to the 10-year mark and live to tell the tale.” The success rate for new businesses is staggeringly low. Much of the risk is due to difficulty for new ideas to catch on. Without impressive marketing tactics and a large initial investment to make that marketing happen, some businesses may never see any customers. To add on to that, growth is even more difficult. With a niche product like the Crema Cup, it may be difficult to get a large audience to accept it into the coffee culture. To add further difficulties, so-called “coffee snobs” are likely to take a polarizing position on whether the product is good or not. If notorious coffee taste-testers gave enough bad reviews to the product, growth would be nearly impossible.

Another important factor for business success is timing. For example, the current economic recession that the United States, and much of the world, is currently facing due to the Coronavirus Pandemic would be a very tough time to enter the market. While it is true that home-made coffee consumption has increased due to stay-at-home orders, it is unlikely that consumers would spend money on a new device when bills are harder to pay than usual.

The final economic hazard is associated with the price of raw materials. The manufactured device is made of polypropylene. Polypropylene is derived from petroleum products called NGLs, otherwise known as Natural Gas Liquids. More specifically, polypropylene is made from propane, which is typically the second most common component in NGLs. Currently, Natural Gas Liquids are extremely cheap due to low energy demand during the Coronavirus Pandemic. The current price for propane is less than $4, about ⅓ of its price in January of 2020 (Energy Information Administration). This will likely lead to a decrease in drilling activity that focuses on production of NGLs. While prices are currently low and are leading to lower polypropylene prices, it is almost a certainty that the price of both propane and polypropylene will increase after demand is back to normal because supply will have decreased dramatically. This increase in the cost of polypropylene would impact the positive economics of the Crema Cup. This impact can be mitigated by finding manufacturers that are willing to give long contracts for the price of polypropylene pellets.

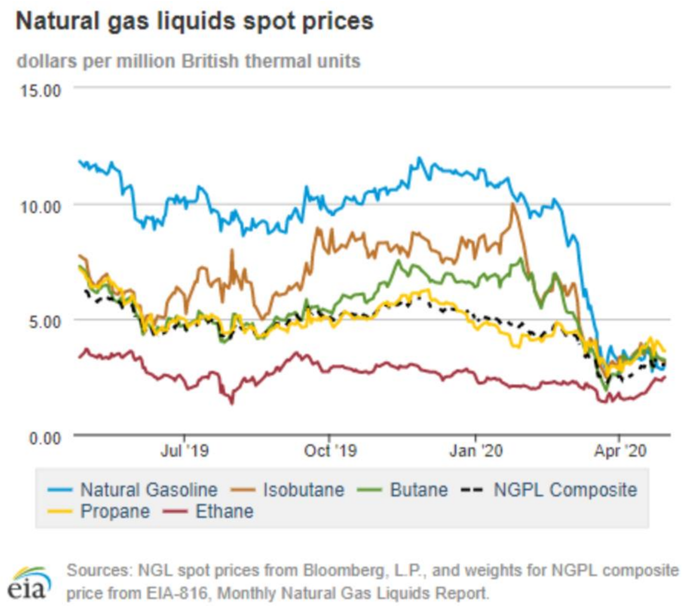

Figure 14: NGL prices over time, according to EIA. The World Health Organization declared a pandemic was declared on March 11, 2020.

Section 6: Conclusions and Recommendations

The main sources of error in the design process are the measuring tools used in the experimentation phase. These are the scale and the process-integrated graduated cylinder (the clear plastic top with the 1 mL engravings). The scale was digital and accurate to the thousands so there is an associated error of 0.0005 grams which was considered negligible. The graduated cylinder propagates an error of 0.5 mL. Altogether the experimentation process can be assumed to have a high accuracy, thus the design decisions made as a product of these results are deemed accurate.

Originally, more testing was scheduled to be done to improve the overall design of the prototype, but circumstances prevented this testing from being completed. To improve the design and results obtained, it is recommended that further testing be done on static mixers. This would include making multiple prototypes with differing static mixer designs. These designs would vary from the square grid that is currently in use, a slanted grid, and the Kenics static mixer to see if the mixing is more efficient.

It is recommended that the project move forward. It has been demonstrated that the product is a viable business idea and that it achieves the desired objectives of increasing crema and limiting grounds from passing through the filters. There is enough demand for it’s parent tool, the AeroPress, that the Crema Cup can succeed as an attachment. Most importantly, the Crema Cup has been proven to outperform its competitors in creating a quality cup of espresso at home for a reasonable cost.

Section 7: Definitions/Nomenclature

AeroPress	Device used for brewing coffee. Prototype is attached for testing purposes.
Crema	The foamy layer on top of coffee that consists of tiny bubbles created by the emulsification of aromatic oils in coffee grounds.
Espresso	Coffee brewed by forcing hot water through finely ground coffee beans.
FMEA	A Failure Mode and Effects Analysis, basically a hazops analysis for the prototype.
Grounds	Finely ground coffee beans.
Injection Mold	Manufacturing process for producing parts by means of injecting molten material into a mold.
Mesh Pre-Filter	Woven metal wire grid used to remove larger particles before interaction with the slot filter.
O-ring	Silicone O-ring used to keep the mesh pre-filter and slot filter confined in their space during brewing.
Slot Filter	Small rectangular grid used to remove small particles before consumer consumption.
Static Mixer	The portion of our device that re-froths the coffee to create a higher volume of crema. It does not consist of any moving parts.

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Section 9: Appendices

Appendix A. Figures and Tables

Table 1: Costing comparisons of various single-serve coffee makers

Product	**Cost**	**Cost of coffee**
AeroPress	$29.95	Filters: $4.99 (350) **$0.02 per cup** Coffee beans: $15.49 for 32 oz **$0.26 per cup - 15 g of beans**
French Press - Bodum	$16.99	Coffee beans: $15.49 for 32 oz **$0.26 per cup - 15 g of beans**
Keurig K-Compact	$59.00	K-Cup: $14.99 (24) **$0.63 per cup**
Mr. Coffee Single Serve Espresso Maker	$99.99	Coffee beans: $15.49 for 32 oz **$0.26 per cup - 15 g of beans**

Table 2: Constant Parameters

Parameter	Item Description or Value
Coffee beans	Kirkland ‘Guatemalan Organic Coffee Beans’
Bean grinder	OXO Brew ‘Conical Burr Coffee Grinder’
Scale	Homgeek ‘Professional Digital Mini Scale’
Paper filters	BUNN ‘Coffee Filters’
Experiment location	2903 North Silkie Place, Tucson AZ, 85719 4160 West Post Road, Chandler AZ, 85226

Table 3: Average weights for both types of paper filters (Large was used for standardized testing)

Paper filter type	Run Number										AVERAGE WEIGHT
	1	2	3	4	5	6	7	8	9	10	
1-cup	1.288	1.296	1.313	1.301	1.307	1.311	1.303	1.293	1.298	1.296	1.3006
Large	1.535	1.583	1.561	1.542	1.577	1.566	1.565	1.569	1.569	1.555	1.5622

Table 4: Experimental results for determining the number of runs for each filter

For filter 80

7 average distribution

Run 1			Run 2			Run 3			Run 4			Run 5		
Weight (g)			Weight (g)			Weight (g)			Weight (g)			Weight (g)		
15.007	Raw beans		15.044	Raw beans		15	Raw beans		14.954	Raw beans		15.007	Raw beans	
14.6	Grounded up		14.791	Grounded up		14.868	Grounded up		14.595	Grounded up		15.352	Grounded up	
4.32	Dried Remains		4.202	Dried Remains		4.153	Dried Remains		4.301	Dried Remains		4.31	Dried Remains	
1.1956	Straight Grounds		1.0776	Straight Grounds		1.0286	Straight Grounds		1.1766	Straight Grounds		1.1856	Straight Grounds	
5	mL	Crema	5.5	mL	Crema	4.5	mL	Crema	5	mL	Crema	5	mL	Crema

Run 6			Run 7		
Weight (g)			Weight (g)		
15.016	Raw beans		14.988	Raw beans	
14.867	Grounded up		14.692	Grounded up	
4.119	Dried Remains		4.138	Dried Remains	
0.9946	Straight Grounds		1.0136	Straight Grounds	
5	mL	Crema	4.5	mL	Crema

Standard Deviation	
Population	0.081414
Size	0.087937

% of grounds that came out in the cup	
Run 1	0.08189
Run 2	0.072855
Run 3	0.069182
Run 4	0.080617
Run 5	0.077228
Run 6	0.0669
Run 7	0.06899

Table 5: Results from mesh filter testing

Mesh Filter Testing									
				Weight (g)					
Set	Run #	Mesh Size	Paper filter info	Whole beans	Ground beans	Dried&used grounds in paper filter	Grounds remaining	Crema volume (mL)	% grounds remaining
1	1	20	2 large	15.007	14.6	4.32	1.1956	5	8.19%
	2	20	2 large	15.044	14.791	4.202	1.0776	5.5	7.29%
	3	30	2 large	15	14.868	4.153	1.0286	4.5	6.92%
	4	30	2 large	14.954	14.595	4.301	1.1766	5	8.06%
	5	40	2 large	15.007	15.352	4.31	1.1856	5	7.72%
	6	40	2 large	15.016	14.867	4.119	0.9946	5	6.69%
	7	60	2 large	14.988	14.692	4.138	1.0136	4.5	6.90%
2	1	20	2 large	15.047	15.033	5.17	2.0456	4	13.61%
	2	20	2 large	14.991	15.058	5.282	2.1576	3.5	14.33%
	3	30	2 large	-	14.458	4.622	1.4976	4	10.36%
	4	30	2 large	-	15.058	4.374	1.2496	4	8.30%
	5	40	2 large	-	14.738	4.714	1.5896	4	10.79%
	6	40	2 large	-	15.022	4.325	1.2006	4	7.99%
	7	60	2 large	-	15.038	4.328	1.2036	3.5	8.00%
	8	60	2 large	-	15.026	4.581	1.4566	4	9.69%
	9	100	2 large	15	14.713	3.856	0.7316	3	4.97%
	10	100	2 large	15.015	15.112	4.199	1.0746	3.5	7.11%
	11	100	2 large	14.995	15.084	4.217	1.0926	3.5	7.24%

Table 6: Results from slot filter testing

Slotted Filter Testing								
Set	Run #	Slot Size	Paper filter info	Ground beans	Dried&used grounds in paper filter	Grounds remaining	Crema volume (mL)	% grounds remaining
1	1	0.004	2 large	14.972	3.588	0.4636	4.5	3.10%
	2	0.004	2 large	15.004	3.517	0.3926	4	2.62%
	3	0.007	2 large	14.994	4.127	1.0026	3.5	6.69%
	4	0.007	2 large	15.007	3.926	0.8016	4	5.34%
	5	0.01	2 large	15	4.552	1.4276	4.5	9.52%
	6	0.01	2 large	14.954	4.339	1.2146	5	8.12%

Table 7: Results from combination filter testing

Combo/French Press Testing									
Set	Run #	Combo	Paper filter info	Whole beans	Ground beans	Dried&used grounds in paper filter	Grounds remaining	Crema volume (mL)	% grounds remaining
Combos	1	80/.01	2 large	15.524	14.798	3.804	0.6796	4.5	4.59%
	2	80/.01	2 large	15.255	14.85	3.979	0.8546	4.5	5.75%
	3	80/.007	2 large	15.27	14.884	3.813	0.6886	4.5	4.63%
	4	80/.007	2 large	15.361	14.965	3.685	0.5606	4	3.75%
	5	80/.004	2 large	15.275	14.984	3.898	0.7736	4.5	5.16%
	6	80/.004	2 large	15.26	15.185	3.813	0.6886	4.5	4.53%
Keurig	1	-	2 large	12.364	12.364	3.1244	0.00	0	0.00%
French Press	1	-	2 large	15.191	15.191	3.988	0.8636	1	5.68%
	2	-	2 large	15.128	15.032	4.59	1.4656	1	9.75%

Table 8: Full Failure Mode and Effects Analysis of the prototype

FMEA

Process/Product Name: Crema Cup Consumer Use

Prepared By: Cremaholics

FMEA Date (Orig.): April 12, 2020

Process Step/Input	Potential Failure Mode	Potential Failure Effects	SEVERITY (1 - 10)	Potential Causes	OCCURRENCE (1 - 10)	Current Controls	DETECTION (1 - 10)	RPN	Action Recommended
What is the process step, change or feature under investigation?	In what ways could the step, change or feature go wrong?	What is the impact on the customer if this failure is not prevented or corrected?		What causes the step, change or feature to go wrong? (how could it occur?)		What controls exist that either prevent or detect the failure?			What are the recommended actions for reducing the occurrence of the cause or improving detection?
Putting Crema Cup together	Misalignment of Aeropress and the added prototype	Leakage during press step could lead to burns	5	Attachment is not tightened all the way	5	Visual and Physical inspection	1	25	Make sure configuration is tightened before use
	Misaligned plunger in AeroPress	Leakage during press step could lead to burns	5	The AeroPress plunger was not fully inserted	5	Visual inspection	1	25	Make sure plunger is straight before use
	O-ring not put in place correctly	Leakage during press step could lead to burns	5	O-ring is too small/big or not in place	4	Visual inspection	1	20	Double-check O-ring in place correctly
	Filters missing or not in place	Excessive grounds in final cup of coffee causing a choking hazard	10	Filters were not placed in the apparatus	1	Visual inspection	1	10	Double-check filters in place correctly
	Finger put in pinch point	Skin on finger could be broken or squeezed	4	The users fingers were placed in between the joints of the Crema Cup and AeroPress	4	Small holes don't allow fingers to easily fit in	1	16	Only place hands on the upper cylinder and lower cylinder
	Breaking the Crema Cup	Plastic pieces could be broken, causing hazards	10	Trying to overtighten the Crema Cup	4	Practice putting it together	1	40	Don't exert too much force on prototype
Pouring coffee grounds into Crema Cup	Spilling grounds	Wasted grounds	3	Mouth of attachment isn't large enough	1	Visual inspection	1	3	Use a funnel to pour grounds into Crema Cup
Pouring heated water into Crema Cup	Spilling water	Lose water for coffee making	4	Carelessness of user	6	An easily recognizable open container	2	48	Attention during pour
		Could cause burns	5	Carelessness of user	4	Visual inspection	1	20	Attention during pour
Brew	Knocking over the filled Crema Cup	Could cause burns, loss of coffee	5	Carelessness of user	4	Common sense	2	40	Be aware of your surroundings
			5	Instability of device	5	Visual and physical inspection	3	75	Use both hands when brewing to add stability
	Touching hot liquid in open material	Could cause burns	5	Carelessness of user	1	Common sense	2	10	Using care when handling hot liquid
	Not enough water	Too concentrated coffee	2	Improper measurements of water	4	Visual inspection	1	8	Be more precise when measuring the amount of water to be used
	Too much water	Hot water could spill/ cause burns	5	Over-filling of the apparatus	5	Visual inspection	1	25	Do not pour water paste a safe height
		Watered-down coffee	3	Improper measurements of water	5	Visual inspection	1	15	Be more precise when measuring the amount of water to be used
Stir grounds and hot water	Spilling grounds and hot water	Decreased amount of coffee produced	3	Stirring too quickly	4	Visual inspection	1	12	Stir ingredients slowly to prevent splashing
Press coffee	Filter clogged	Coffee is difficult to press or will not press	3	Filter was not properly cleaned	4	Filters in series	2	24	Clean out filters after each use
	O-ring heat failure	Leakage during press step	5	O-ring breakdown over time	5	Visual inspection, lack of suction	3	75	Changing O-ring every six months
	Not pressing the plunger vertically	Leakage during press step	5	Uneven application of pressure to plunger by user	5	Handles that can easily be pressed downwards	2	50	Use care and a steady hand
Pour brewed coffee out of Crema Cup	Spilling the coffee	Hot liquid could cause burns	5	Carelessness of user	3	Visual inspection	2	30	Use a cup that has a wide mouth/pour slowly
Take apart Crema Cup	Leftover hot coffee and grounds	Burns from handling hot liquids	5	Lack of visual inspection	3	Visual inspection	1	15	After pouring into the coffee mug, pour any leftover liquids into the sink before taking the crema cup apart
Clean Crema Cup	Hot plastic	Burn skin	5	Not waiting for cool-down of prototype	3	Visual inspection/Finger touch	1	15	Allow apparatus to reach room temperature before cleaning

Table 9: The year over year economics of manufacturing and sales.

Year	Units Sold	Cost (Scaled)	Sales	Profit	Rolling ROI
0	1000	$ 49,635.00	$ 29,950.00	$ (19,685.00)	-40%
1	2722	$ 33,034.17	$ 81,530.56	$ 48,496.39	35%
2	4444	$ 53,933.33	$ 133,111.11	$ 79,177.78	79%
3	6167	$ 74,832.50	$ 184,691.67	$ 109,859.17	103%
4	7889	$ 95,731.67	$ 236,272.22	$ 140,540.56	117%
5	9611	$ 116,630.83	$ 287,852.78	$ 171,221.94	125%
6	11333	$ 137,530.00	$ 339,433.33	$ 201,903.33	130%
7	13056	$ 158,429.17	$ 391,013.89	$ 232,584.72	134%
8	14778	$ 179,328.33	$ 442,594.44	$ 263,266.11	137%
9	16500	$ 200,227.50	$ 494,175.00	$ 293,947.50	138%

Figure 1: Prototype attached to the AeroPress

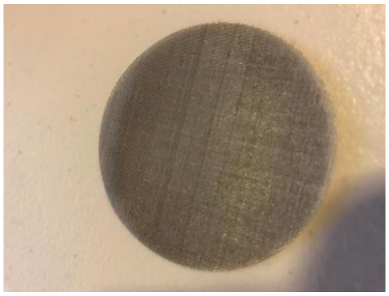
Figure 2: 80 mesh Pre-Filter

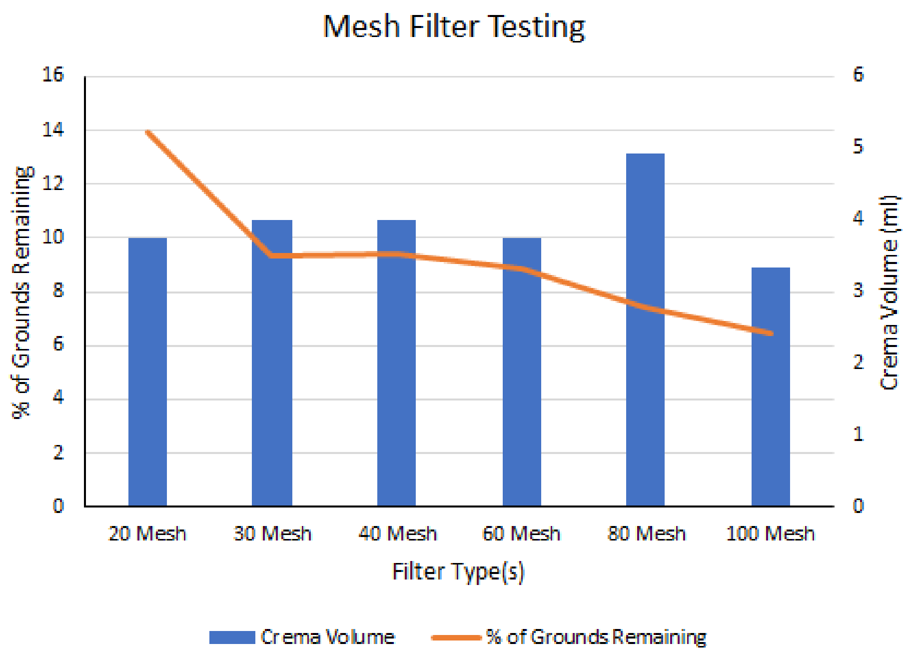

Figure 3: Graphed results of all filter testing

Figure 4: 0.004” Slot Filter

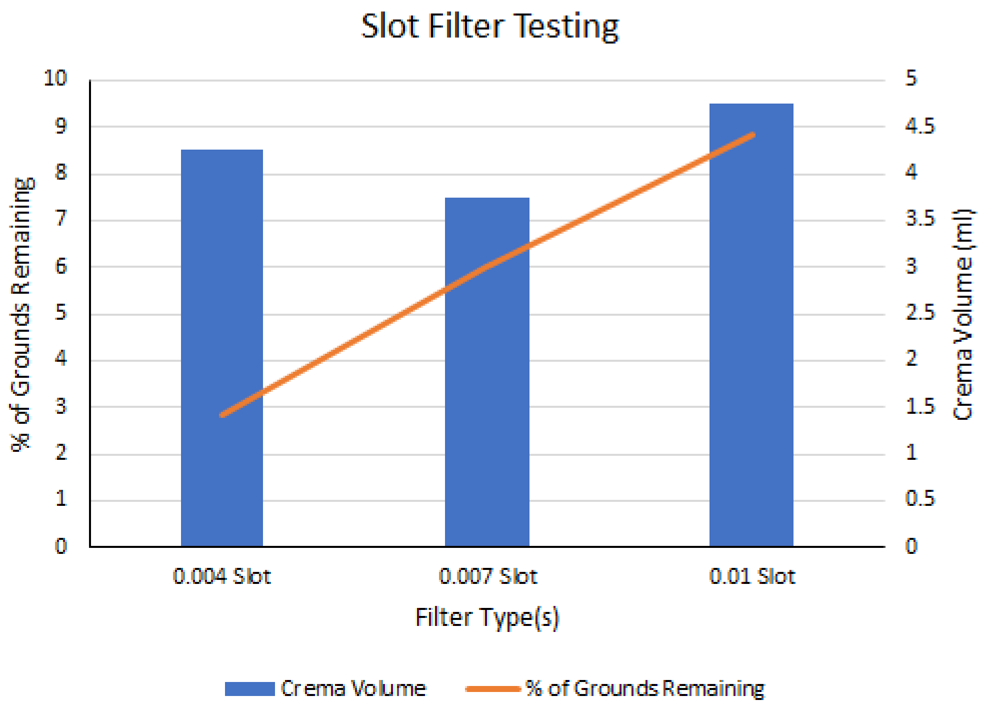

Figure 5: Slot Filter Testing Results

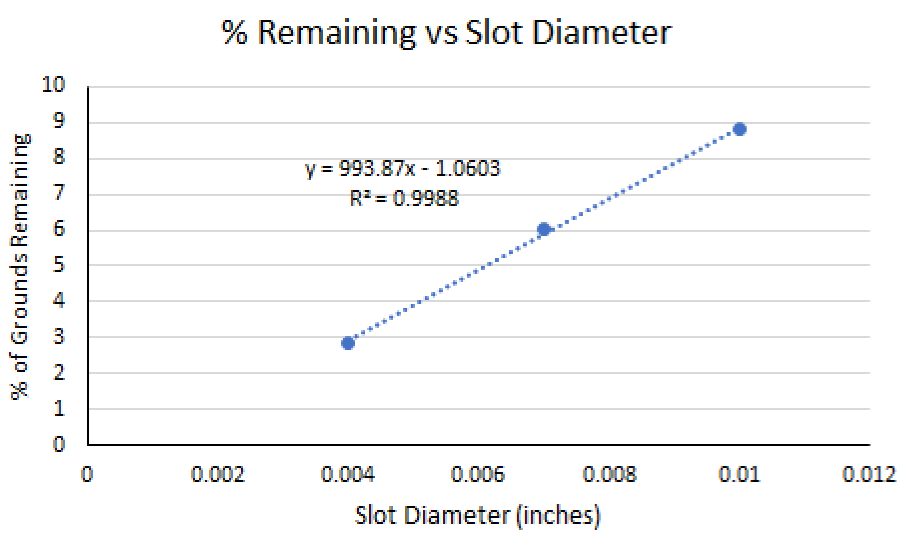

Figure 6: Percent Remaining vs Slot Diameter

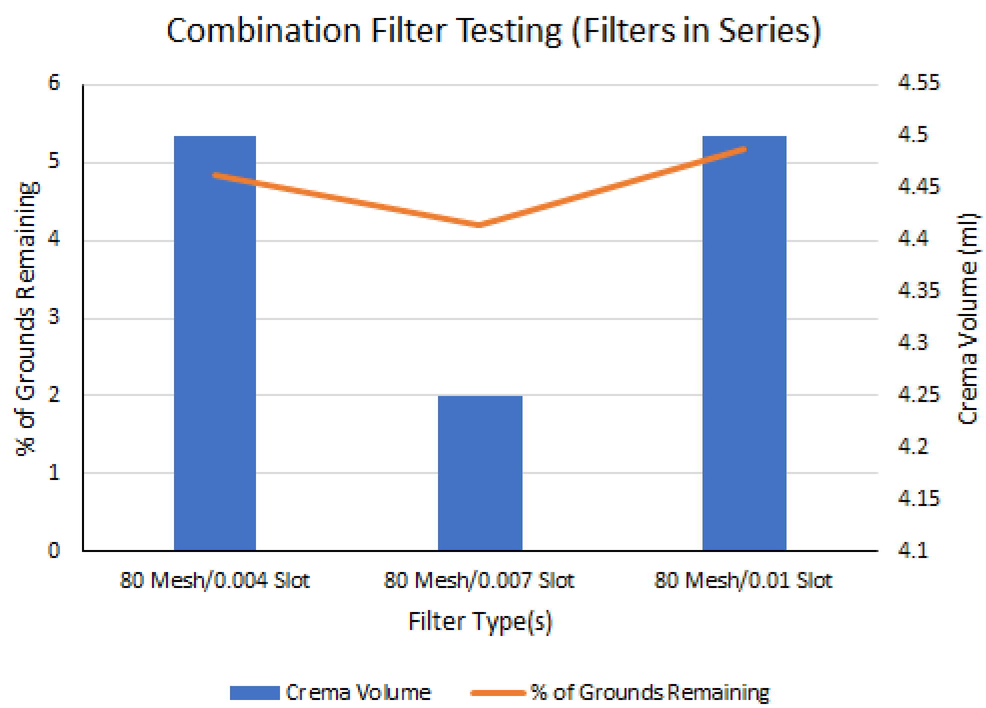

Figure 7: Filters in Series Testing Results

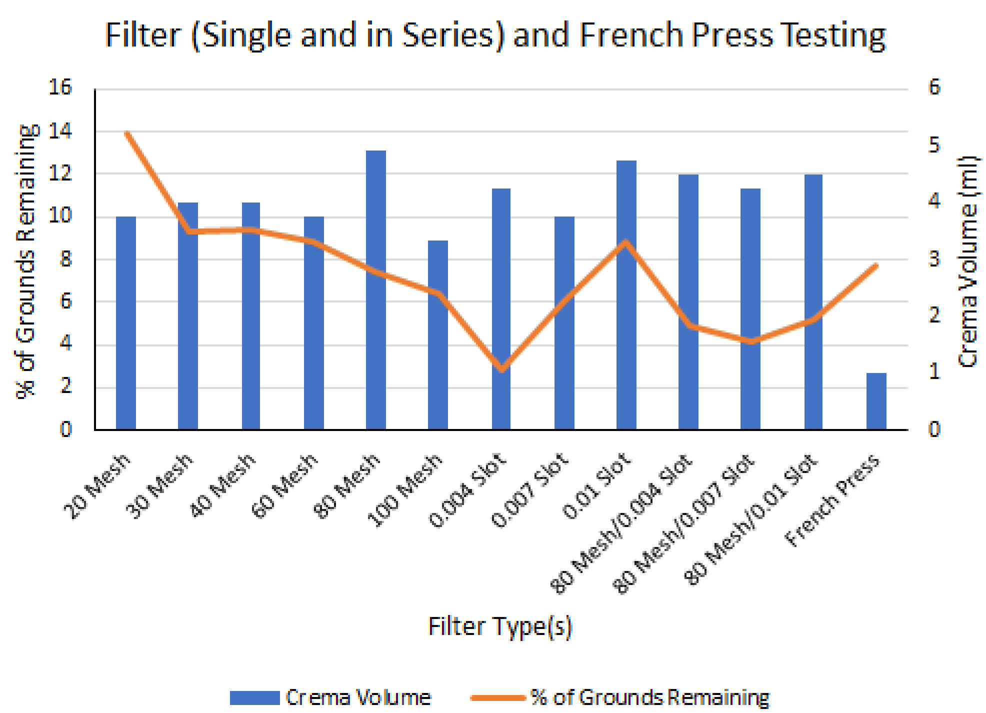

Figure 8: Overall results from testing, % Ground Remains and Crema Volume vs Filter Type

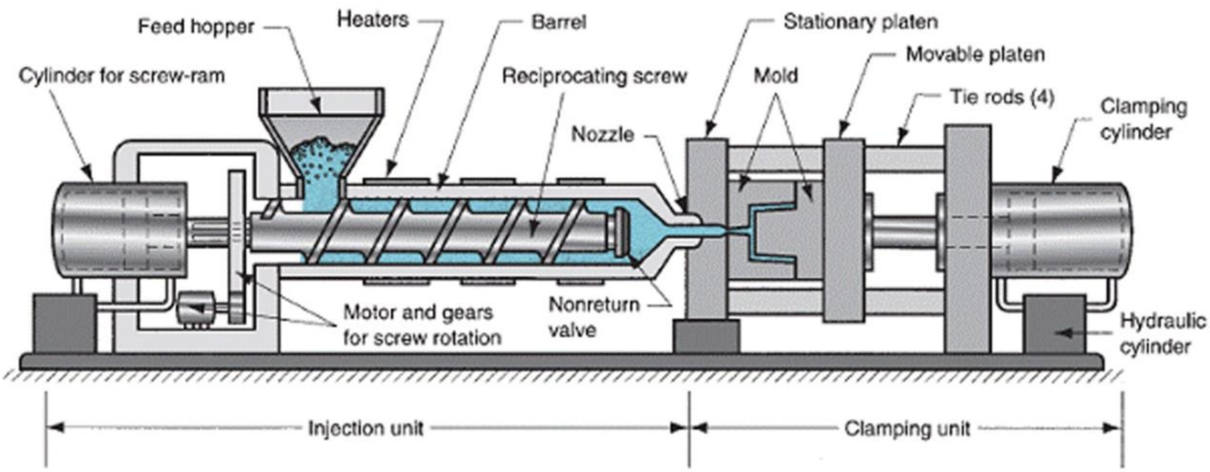

Figure 9: Injection Molding Machine

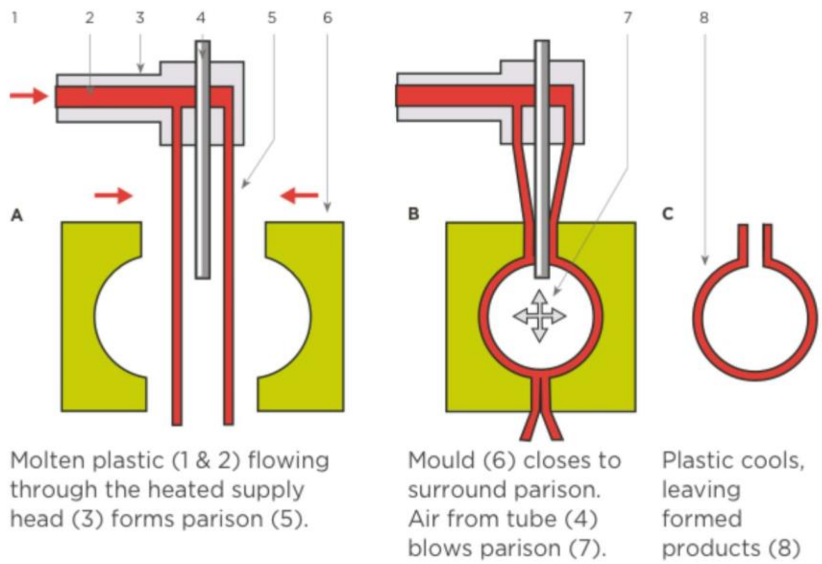

Figure 10: Injection Step in the IM Process

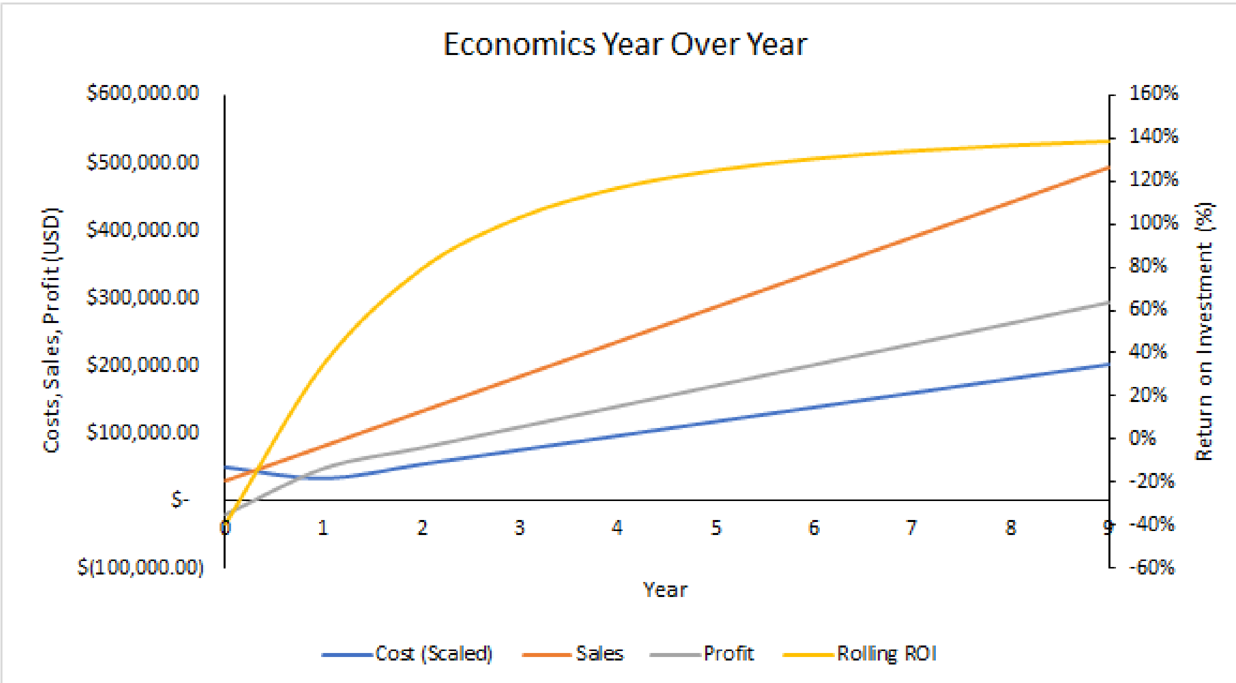

Figure 11: Costs, Sales, Profits, and Rolling Return on Investment

Figure 12: Picture of Typical Injection Mold (Liisa)

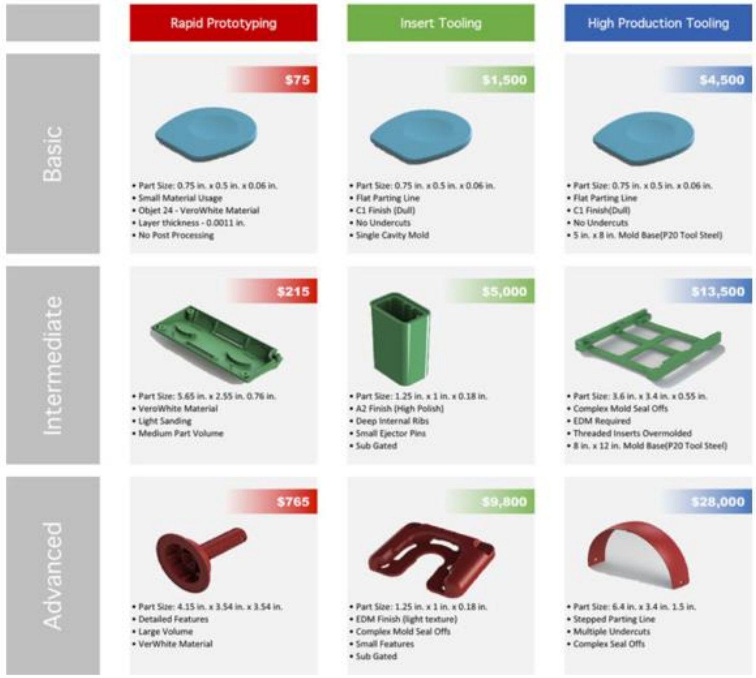

Figure 13: Estimations Of Typical Injection Molds

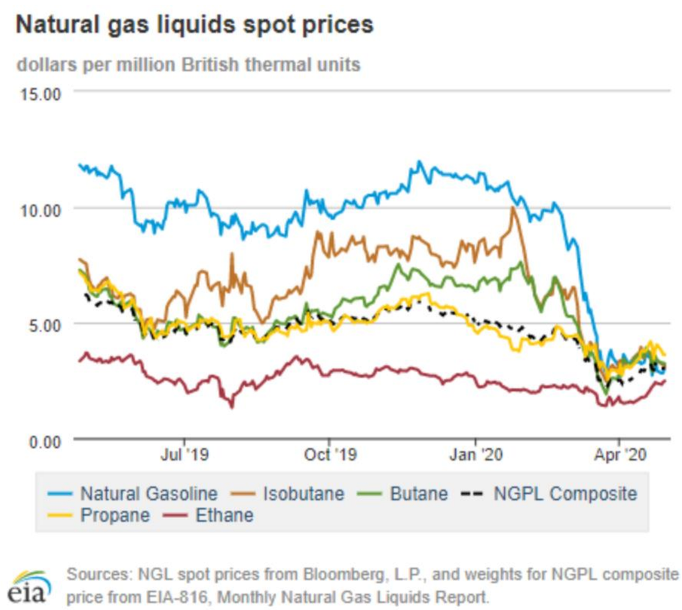

Figure 14: NGL prices over time, according to EIA. The World Health Organization declared a pandemic was declared on March 11, 2020.

Appendix B. Supplementary Figures

Figure A: Crema Cup prototype

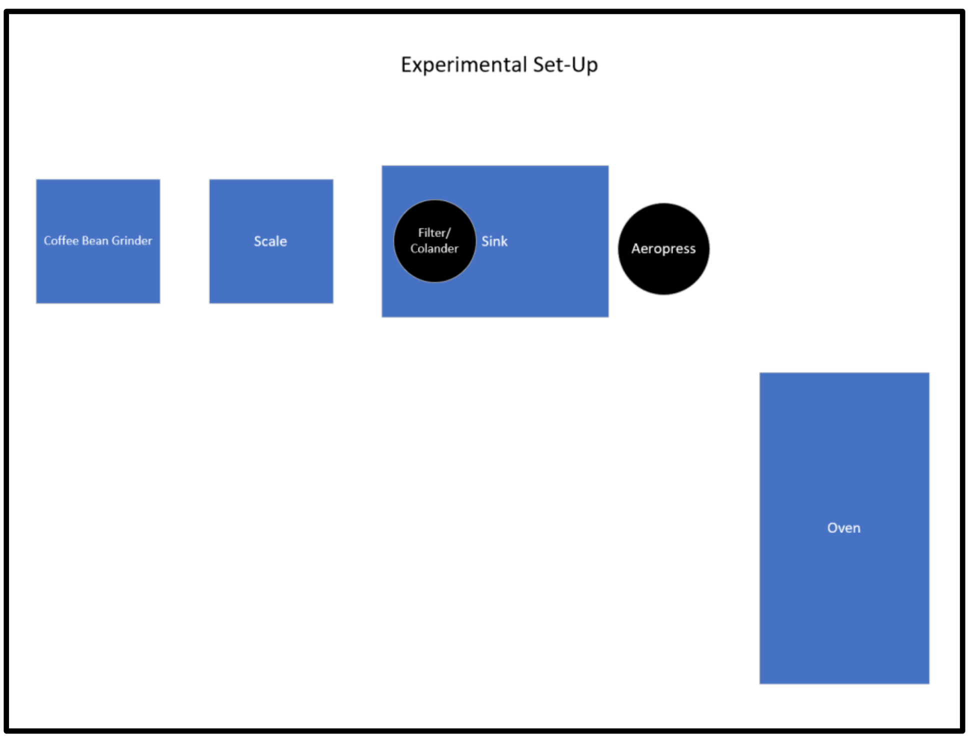

Figure B: Experimental setup for testing

Figure C: AeroPress

Figure D: Top view of static mixing grid in attachment

Figure E: Crema in the AeroPress chamber during the brewing phase

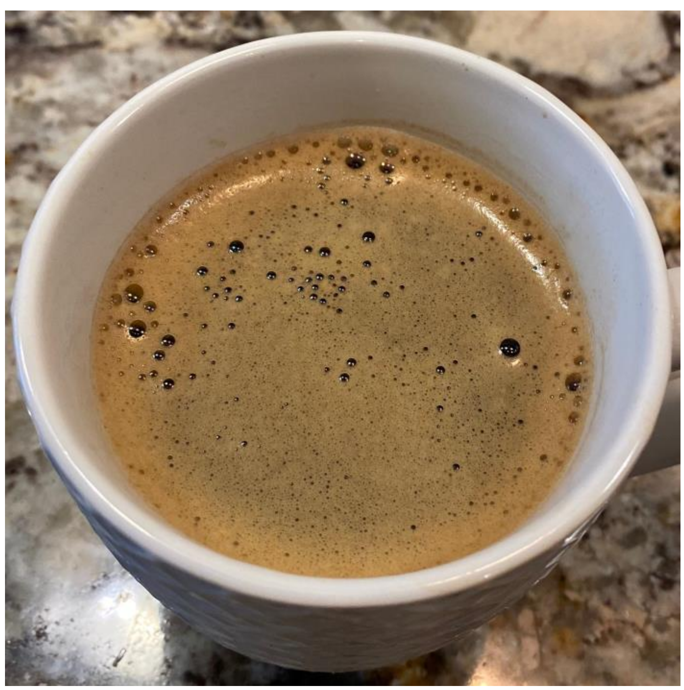
Figure F: Crema after pouring from the Crema Cup

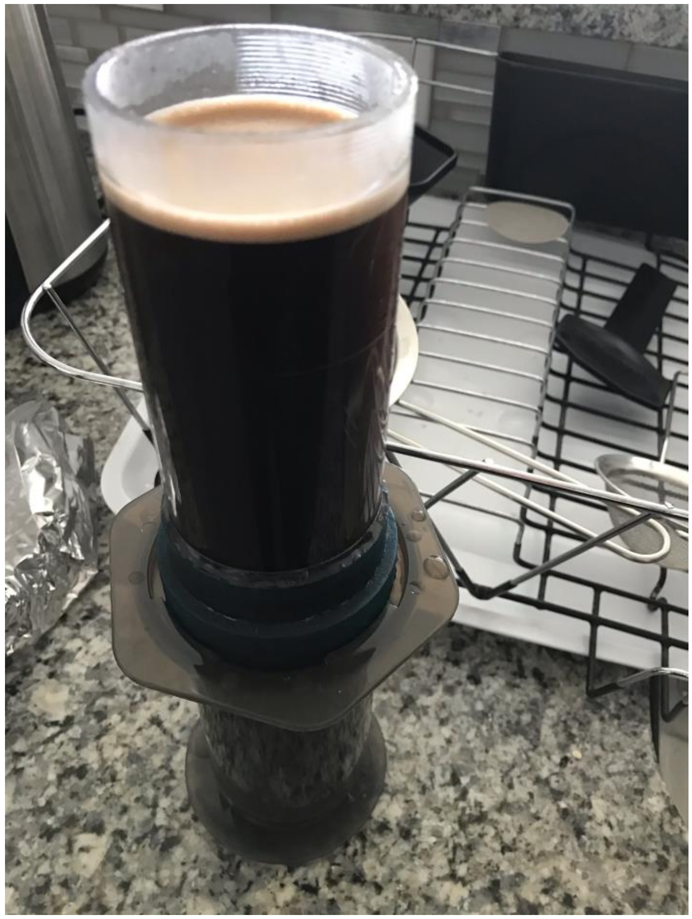

Figure G: Example of how crema is measured using the 1 mL markings - crema measured at the **meniscus** of the crema

Figure H: Crema in Crema Cup

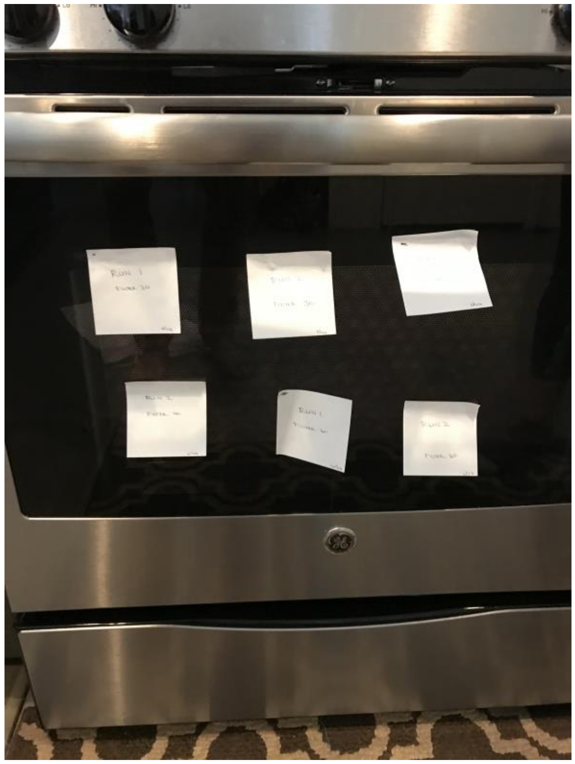

Figure I: Drying process in oven

Figure J: Crema measurement

Figure K: Filter in filter housing (quarter turn locking method shown), secured by o-ring

Appendix C. Equations

Below is a list of all equations used in the document and in the spreadsheet:

(1)

(2)

(3)

(4)

(5)

(6)

(7)

Appendix D. Spreadsheets

Below are the pages of the calculations spreadsheet that have calculations on them. Other pages are associated with raw data and the formation of tables and figures. Page one shows the results of filter testing. The percentage of grounds remaining is calculated with Equation 7. Page two calculates economics. The references are listed in the document, and calculations use Equations 4 and 5.

Page 1: Results Tables

Mesh Filter Testing									
				Weight (g)					
Set	Run #	Mesh Size	Paper filter info	Whole beans	Ground beans	Dried&used grounds in paper filter	Grounds remaining	Crema volume (mL)	% grounds remaining
1	1	20	2 large	15.007	14.6	4.32	1.1956	5	8.19%
	2	20	2 large	15.044	14.791	4.202	1.0776	5.5	7.29%
	3	30	2 large	15	14.868	4.153	1.0286	4.5	6.92%
	4	30	2 large	14.954	14.595	4.301	1.1766	5	8.06%
	5	40	2 large	15.007	15.352	4.31	1.1856	5	7.72%
	6	40	2 large	15.016	14.867	4.119	0.9946	5	6.69%
	7	60	2 large	14.988	14.692	4.138	1.0136	4.5	6.90%
2	1	20	2 large	15.047	15.033	5.17	2.0456	4	13.61%
	2	20	2 large	14.991	15.058	5.282	2.1576	3.5	14.33%
	3	30	2 large	-	14.458	4.622	1.4976	4	10.36%
	4	30	2 large	-	15.058	4.374	1.2496	4	8.30%
	5	40	2 large	-	14.738	4.714	1.5896	4	10.79%
	6	40	2 large	-	15.022	4.325	1.2006	4	7.99%
	7	60	2 large	-	15.038	4.328	1.2036	3.5	8.00%
	8	60	2 large	-	15.026	4.581	1.4566	4	9.69%
	9	100	2 large	15	14.713	3.856	0.7316	3	4.97%
	10	100	2 large	15.015	15.112	4.199	1.0746	3.5	7.11%
	11	100	2 large	14.995	15.084	4.217	1.0926	3.5	7.24%

Combo/French Press Testing									
Set	Run #	Combo	Paper filter info	Whole beans	Ground beans	Dried&used grounds in paper filter	Grounds remaining	Crema volume (mL)	% grounds remaining
Combos	1	80/.01	2 large	15.524	14.798	3.804	0.6796	4.5	4.59%
	2	80/.01	2 large	15.255	14.85	3.979	0.8546	4.5	5.75%
	3	80/.007	2 large	15.27	14.884	3.813	0.6886	4.5	4.63%
	4	80/.007	2 large	15.361	14.965	3.685	0.5606	4	3.75%
	5	80/.004	2 large	15.275	14.984	3.898	0.7736	4.5	5.16%
	6	80/.004	2 large	15.26	15.185	3.813	0.6886	4.5	4.53%
Keurig	1	-	2 large	12.364	12.364	3.1244	0.00	0	0.00%
French Press	1	-	2 large	15.191	15.191	3.988	0.8636	1	5.68%
	2	-	2 large	15.128	15.032	4.59	1.4656	1	9.75%

Slotted Filter Testing								
Set	Run #	Slot Size	Paper filter info	Ground beans	Dried&used grounds in paper filter	Grounds remaining	Crema volume (mL)	% grounds remaining
1	1	0.004	2 large	14.972	3.588	0.4636	4.5	3.10%
	2	0.004	2 large	15.004	3.517	0.3926	4	2.62%
	3	0.007	2 large	14.994	4.127	1.0026	3.5	6.69%
	4	0.007	2 large	15.007	3.926	0.8016	4	5.34%
	5	0.01	2 large	15	4.552	1.4276	4.5	9.52%
	6	0.01	2 large	14.954	4.339	1.2146	5	8.12%

Page 2: Economics

Description	Amount	Reference or Description
Initial Startup Cost (injection mold):	$ 37,500.00	Rex Plastics
Cost of materials per Crema Cup (plastic):	$ 5.00	Techmold
Cost of slot filters per Crema Cup:	$ 2.00	Estimate for specialty part
Cost of mesh filters per Crema Cup:	$ 0.47	McMaster-Carr
Cost of O-ring per Crema Cup:	$ 0.12	McMaster-Carr
Cost of Packaging per Crema Cup:	$ 0.50	Approximation from packaging engineer
Total Cost per Crema Cup:	$ 8.09	
Number of AeroPresses Sold per Year:	250,000.00	Rough estimate based on Aeropress yearly profits and unit price
Assumption of Market Capture:	3.5%	
Crema Cups Sold:	8,750.00	
Cost to User (sale cost):	$ 29.95	Quote from vendor
Cost per year to produce Crema Cups (baseline):	$ 70,787.50	
Cost per year to produce Crema Cups (scaled by 50%):	$ 106,181.25	Scaled to account for storage, marketing and logistics
Annual Sales	$ 262,062.50	
Total 10 year investment:	$ 1,099,312.50	
10 Year Revenue:	$ 2,620,625.00	
10 Year Profit:	$ 1,521,312.50	
ROI after 10 years:	138%	

Year	Number Sold	Cost (Scaled)	Sales	Profit	Rolling ROI
0	1000	$ 49,635.00	$ 29,950.00	$ (19,685.00)	-40%
1	2722.222222	$ 33,034.17	$ 81,530.56	$ 48,496.39	35%
2	4444.444444	$ 53,933.33	$ 133,111.11	$ 79,177.78	79%
3	6166.666667	$ 74,832.50	$ 184,691.67	$ 109,859.17	103%
4	7888.888889	$ 95,731.67	$ 236,272.22	$ 140,540.56	117%
5	9611.111111	$ 116,630.83	$ 287,852.78	$ 171,221.94	125%
6	11333.33333	$ 137,530.00	$ 339,433.33	$ 201,903.33	130%
7	13055.55556	$ 158,429.17	$ 391,013.89	$ 232,584.72	134%
8	14777.77778	$ 179,328.33	$ 442,594.44	$ 263,266.11	137%
9	16500	$ 200,227.50	$ 494,175.00	$ 293,947.50	138%

Appendix E. Meeting Minutes

Team Members' Names
Mak Smith
Richie Curradi
Nate Marshall
Mikayla Caputo

Meeting 1*

Meeting Date: *1/25/2020*	**Start Time: *1 PM* End Time: *2 PM*** **Summary of Meeting**
1. Attendance	*All present*
2. Purpose of Meeting	*To meet with mentor and discuss project objectives, criteria, and constraints.*
3. Discuss work completed since last meeting.	*None. First work meeting.*
4. Summarize work completed during meeting	*Spoke with Dr. Marshall about the project and got a high-level overview of the design criteria and constraints.*
5. Review action items to be completed after meeting	*Each member will perform research and bring 10 research materials to the next meeting.*
6. Schedule next meeting	*Friday 1/31/2020 at 12:30 PM*
7. Recording secretary	*Mak Smith*

*there was also a meeting prior to this to complete the team charter (all attended)

Meeting 2

Meeting Date: *1/31/2020*	**Start Time: *12:30 PM* End Time: *2 PM*** **Summary of Meeting**
1. Attendance	*All Present*
2. Purpose of Meeting	*To discuss the upcoming objectives and deadlines for our senior design project (project timeline/Gantt Chart). Also, we want to establish reasonable objectives to complete each week.*
3. Discuss work completed since last meeting.	*We worked together to complete assignment: Objectives, criteria, and constraints. We all also found 10 unique references and brought them to the meeting for discussion.*

4. Summarize work completed during meeting	*With Dr. Marshall guidance we have established how we want to move forward in our testing of the original prototype and the slight variants we wish to make upon the original piece.*
5. Review action items to be completed after meeting	*On Saturday 2/1/2020 we will obtain the needed material to conduct tests: coffee beans, DI water, timer, and acetone. On Sunday 2/2/2020 we will conduct tests with the original prototype. In these tests we will be observing the leftover grounds in the cup. We will be using a variety of filters to establish which mesh size configuration has the optimal production of crema.*
6. Schedule next meeting	*Next Friday, 2/7/2020 @12:30 PM*
7. Recording secretary	*Richie Curradi*

Meeting 3

Meeting Date: *2/2/2020*	**Start Time: *9:00 am* End Time: *12:00 pm* Summary of Meeting**
1. Attendance	*All students present*
2. Purpose of Meeting	*Filter testing and prototype practice*
3. Discuss work completed since last meeting.	*We purchased goods for filter testing: coffee beans, distilled water*
4. Summarize work completed during meeting	*Tested mesh filters, but did not weigh the products*
5. Review action items to be completed after meeting	*After meeting, we all need to brainstorm how to test more efficiently, and how we can weight the grounds*
6. Schedule next meeting	*Friday, 2/7/2020, 12:00pm in Fine Arts Library*
7. Recording secretary	*Nate Marshall*

Meeting 4

Meeting Date: *2/7/2020*	**Start Time: *12:00 pm* End Time: *1:00 pm* Summary of Meeting**
1. Attendance	*All students present*

2. Purpose of Meeting	*Update our sponsor on the testing that has been done and some issues that we came across. Also, go over the content and responsibilities for the presentation.*
3. Discuss work completed since last meeting.	*Last Sunday, we met up to do some testing. We tested different filters to compare the amount of coffee grounds that were left at the bottom of the cup.*
4. Summarize work completed during meeting	*We started our progress presentation and split up the slides to be completed by each member.*
5. Review action items to be completed after meeting	*Each member will complete their slides for the presentation. Sometime next week, we plan on performing more experiments.*
6. Schedule next meeting	*Wednesday, 2/12/2020*
7. Recording secretary	*Mikayla Caputo*

Meeting 5

Meeting Date: *2/11/2020*	**Start Time: *11 AM* End Time: *12 PM*** **Summary of Meeting**
1. Attendance	*All members plus mentor*
2. Purpose of Meeting	*To discuss the upcoming experiments and order supplies*
3. Discuss work completed since last meeting.	*Presentation was finished and we presented it to Dr. Brush on Monday, Feb 10.*
4. Summarize work completed during meeting	*We ordered filters, strainers, and a scale with higher precision.*
5. Review action items to be completed after meeting	*Order delivery and alternatives started.*
6. Schedule next meeting	*2/13/2020 at noon*
7. Recording secretary	*Nate Marshall*

Meeting 6

Meeting Date: ***2/13/2020***	**Start Time:** ***12 PM*** **End Time:** ***4 PM*** **Summary of Meeting**
1. Attendance	*All student members*
2. Purpose of Meeting	*The test filters and set up experimental plan*
3. Discuss work completed since last meeting.	*Experimental plan was started.*
4. Summarize work completed during meeting	*A distribution of filter tests to determine the standard deviation of testing was done, and other filters were tested for grounds passing through and crema volume.*
5. Review action items to be completed after meeting	*Experimental plan and design description should be finished.*
6. Schedule next meeting	*TBD - 413 test week*
7. Recording secretary	*Nate Marshall*

Meeting 7

Meeting Date: ***2/21/2020***	**Start Time:** ***1 PM*** **End Time:** ***2 PM*** **Summary of Meeting**
1. Attendance	*All student members*
2. Purpose of Meeting	*Discuss the results of our previous experiment days. Receive feedback from Dr. Marshall on how we can fix a few problems we ran into. Receive feedback on current results. Lastly, come up with a plan for filters that will be tested on the upcoming testing day (2/23).*
3. Discuss work completed since last meeting.	*Started an experimental plan for our filters, and tested filters of mesh 80 for a distribution curve, and filter 100.*
4. Summarize work completed during meeting	*Discussion of current progress in optimizing our prototype.*
5. Review action items to be completed after meeting	*Test the remaining individual filters to determine the ground remains for individual filter configurations (Filters 20-100). On our testing day 2/23, ran into problems with our Prototype, and worked the entire experimental day to fix the problem.*

6. Schedule next meeting	*Friday, 2/27/2020, 12:00pm in Fine Arts Library*
7. Recording secretary	*Richie Curradi*

Meeting 8

Meeting Date: *2/27/2020*	**Start Time: *1 pm* End Time: *4 pm* Summary of Meeting**
1. Attendance	*Everyone*
2. Purpose of Meeting	*To complete mesh single filter testing*
3. Discuss work completed since last meeting.	*Reviewed and provided feedback with another group*
4. Summarize work completed during meeting	*Single filter testing*
5. Review action items to be completed after meeting	*Feedback should be reviewed and incorporated*
6. Schedule next meeting	*Thursday 3/5 at 1 pm*
7. Recording secretary	*Mak Smith*

Meeting 9

Meeting Date: *3/4/2020*	**Start Time: *4* End Time: *5* Summary of Meeting**
1. Attendance	*All members*
2. Purpose of Meeting	*To finish the alternative assignment (revision)*
3. Discuss work completed since last meeting.	*Reviewed feedback from another group and did our best to implement that into our current work. Submitted this revision of our alternative assignment. Also met as a group to take our senior class photo.*
4. Summarize work completed during meeting	*Finish alternative assignment revision*

5. Review action items to be completed after meeting	*Working forward on optimizing our prototype.*
6. Schedule next meeting	*TBD since outbreak of coronavirus*
7. Recording secretary	*Richie Curradi*

Meeting 10

Meeting Date: *3/20/20*	**Start Time: *11:30am* End Time: *12:30am*** **Summary of Meeting**
1. Attendance	*All members*
2. Purpose of Meeting	*Touch up presentation and practice presentation.*
3. Discuss work completed since last meeting.	*We looked over the presentation (progress 2) and discussed disruptions due to the coronavirus.*
4. Summarize work completed during meeting	*The finished all data analysis up to date and created a presentation.*
5. Review action items to be completed after meeting	*We need to decide on what aspects to move forward with on paper.*
6. Schedule next meeting	*Wednesday, March 25*
7. Recording secretary	*Nate*

Meeting 11

Meeting Date: *3/26/2020*	**Start Time: *2:00 pm* End Time: *3:00 pm*** **Summary of Meeting**
1. Attendance	*All members*
2. Purpose of Meeting	*Discuss how we are going to proceed with our project.*
3. Discuss work completed since last meeting.	*We presented our second presentation and discussed what we can do for the project in these circumstances.*

4. Summarize work completed during meeting	*We met with our sponsor and discussed what we can do for the project in the meantime. We decided that we would continue our research, create a few designs in solidworks, and possibly continue some testing.*
5. Review action items to be completed after meeting	*Each member will do research on a specific aspect of the process: static mixers, market data, etc. Nate might do some testing with Richie or Mak.*
6. Schedule next meeting	*Wednesday, April 1*
7. Recording secretary	*Mikayla*

Meeting 12

Meeting Date: *4/2/2020*	**Start Time: *12 PM* End Time: *1 PM* Summary of Meeting**
1. Attendance	*Nate, Richie, Mikayla, Mak*
2. Purpose of Meeting	*Discuss plans and assign deliverables*
3. Discuss work completed since last meeting.	*Nate performed testing and finished filter combination testing*
4. Summarize work completed during meeting	*Assigned deliverables to each team member*
5. Review action items to be completed after meeting	*Deliverables and award self-noms*
6. Schedule next meeting	*4/8/2020*
7. Recording secretary	*Mak*

Meeting 13

Meeting Date: *4/9/20*	**Start Time: *6:15* End Time: *7:15* Summary of Meeting**
1. Attendance	*Everyone*
2. Purpose of Meeting	*Discuss future steps for HAZOP and Progress Presentation 3. Also, discuss final results and calculations.*

3. Discuss work completed since last meeting.	*Final testing, patent search, market research, injection molding basics.*
4. Summarize work completed during meeting	*Set up times for presentation and meetings.*
5. Review action items to be completed after meeting	*HAZOP and progress presentation.*
6. Schedule next meeting	*Next friday*
7. Recording secretary	*Nate*

Meeting 14

Meeting Date: *4/12/20*	**Start Time: *7:00* End Time: *9:30* Summary of Meeting**
1. Attendance	*Everyone*
2. Purpose of Meeting	*finish HAZOP and progress presentation*
3. Discuss work completed since last meeting.	*More research and analysis of data.*
4. Summarize work completed during meeting	*HAZOP and progress presentation 3*
5. Review action items to be completed after meeting	*prepare for presentation and work on poster brainstorming*
6. Schedule next meeting	*9:40am monday morning (4/13)*
7. Recording secretary	*Nate*

Meeting 15

Meeting Date: *4/17/20*	**Start Time: *Record time meeting started* End Time: *Record meeting end time* Summary of Meeting**

1. Attendance	*Everyone*
2. Purpose of Meeting	*To work on finishing the poster for senior design.*
3. Discuss work completed since last meeting.	*Finish HAZOP assignment*
4. Summarize work completed during meeting	*Worked towards completing the outline provided for our senior design poster presentation.*
5. Review action items to be completed after meeting	*Each member will receive a specific part of the poster to talk over for our senior design video.*
6. Schedule next meeting	*TBD*
7. Recording secretary	*Richie*

Meeting 16

Meeting Date: ***4/24/20***	**Start Time:** ***2:00pm*** **End Time:** ***3:00pm*** **Summary of Meeting**
1. Attendance	*Nate, Mak, Richie*
2. Purpose of Meeting	*To decide on the plans for writing the final report.*
3. Discuss work completed since last meeting.	*None - finally got a small break.*
4. Summarize work completed during meeting	*Decided on how to write report, when to meet, and how we will complete other deadlines.*
5. Review action items to be completed after meeting	*Start a google doc and begin writing each section individually.*
6. Schedule next meeting	*Wednesday 2pm 4/29*
7. Recording secretary	*Nate*

Meeting 17

Meeting Date: *Multiple (4)*	**Summary of Meeting**
1. Attendance	*Nate, Mak, Mikayla, Richie*
2. Purpose of Meeting	*Writing final report and working on presentation*
3. Discuss work completed since last meeting.	*Video presentation for Design Day*
4. Summarize work completed during meeting	*Writing the final report and working on the final presentation*
5. Review action items to be completed after meeting	*Get ready to work on the Lab Safety Audit and final presentation*
6. Schedule next meeting	*Tuesday 7 PM*
7. Recording secretary	*Mak*